The lower tertiary Eyre formation of the Southwestern great Artesian basin

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THE LOWER TERTIARY EYRE FORMATION OF THE SOUTHWESTERN GREAT ARTESIAN BASIN

by H. WOPFNER, R. CALLEN, and WAYNE K. HARRIS

(With 1 Plate and 19 Figures)

ABSTRACT

The term 'Eyrian Series', proposed by Woolnough and David in 1926, is here redefined in terms of the Australian Code of Stratigraphic Nomenclature. In conformity with the code the orignal term is changed to *Eyre Formation*.

The Eyre Formation is defined as the sequence, consisting of mature conglomerate, quartz sandstone, carbonaceous siltstone, and lignite, which rests unconformably on late Cretaceous or older rocks. Highly polished clastic components are typical. The top of the Eyre Formation is identified either by its contact with a Miocene carbonate-shale sequence or by a quartzitic palaeosol.

Detailed descriptions of type and reference sections are given. Microfloras show that the formation is of Paleocene and Eocene age.

The Eyre Formation was deposited under fluviatile and to a lesser degree lacustrine conditions and formed an almost continuous sediment blanket from southwest Queensland to the western and southern margins of the Great Artesian Basin. The thickness of the formation was influenced by syndepositional epeirogenic movements.

Climate was warm-temperate with at least seasonally high precipitation. Probable source areas and transport paths are suggested and correlations with equivalent units outside the Great Artesian Basin are discussed.

INTRODUCTION

Early Tertiary rocks cover large parts of the Great Artesian Basin, and although their total thickness rarely exceeds 150 m they are of economic as well as scientific importance.

They have played a major role in the recognition and mapping of surface structures (Jack, 1925; Wopfner, 1960) and thus were vital in the promotion of petroleum exploration (Sprigg, 1958) which led ultimately to the discovery of large hydrocarbon deposits in northeasternmost South Australia (Wopfner, 1966; Martin, 1967). Within the area of the Cooper Basin their base reflects the deeply buried Permian structure, suggesting rejuvenation of tectonism along Permian trends in Tertiary time. This may have considerable bearing on factors controlling the accumulation or retention of hydrocarbons under a given trap geometry and hydrodynamic gradient. In more recent years they have become one of the major targets in the search for sedimentary uranium deposits and they are still being most actively explored along the southern and southwestern margin of the basin.

In the course of recent geological investigations of the South Australian portion of the Great Artesian Basin a number of new stratigraphic terms have been used to identify the early Tertiary sediments. Some of these terms

were formal, for instance Murnpeowie Formation, introduced by Forbes (1966) in the geological map of the Maree area, or Macumba Sandstone, used by Freytag *et al.* (1967) in the geological map of the Oodnadatta region. In other areas informal names had been in use (Wopfner, 1958) and some were being formalized. Each name more or less corresponds to an area in which Lower Tertiary sediments are exposed extensively in surface anticlines. Recent expansion of drilling coverage showed that the same sediments continue beneath the surface, and form a continuous blanket over the Mesozoic rocks. It could be established also that they all resulted from essentially the same depositional phase, although the detrital material may have originated from different provenances.

As geological work progressed outward from the major surface exposures it became increasingly apparent that these different names, identifying essentially the same rock unit, would clash somewhere between their 'points of origin'. As there are no natural lines of division between adjacent 'formations', either artificial lines of demarcation (e.g. boundaries of map sheets) would have to be accepted or a uniform name applicable for the whole area of distribution would have to be found.

After discussions within the South Australian Geological Survey, and with members of the Sub-committee on Stratigraphic Nomenclature, it was decided that a uniform rock stratigraphic name applicable to all of the South Australian and adjoining portions of the Great Artesian Basin was desirable—if so, the existing stratigraphic nomenclature had to be completely revised; but it appeared inadvisable to extend an existing local name to cover the whole region, particularly since an appropriate stratigraphic name already existed.

The term 'Eyrian Series' had been proposed by Woolnough & David (1926) and had been generally accepted and widely used for more than 25 years (see below). As its establishment and general use antedates the first publication of the Australian Code of Stratigraphic Nomenclature in 1954, it must be formalized and revised to bring it into conformity with the Code.

Therefore we propose that the new form of the name shall be *Eyre Formation,* and the purpose of this paper is to define the name, identify its rock and fossil contents, and designate the area to which it shall apply.

In taking this step we were guided by the Australian Code of Stratigraphic Nomenclature (1964, p. 166), which states:

'Rock unit names which were established before the publication of the Australian Code and which were at the time of their erection properly defined will be inherently valid. Those which were not properly defined and those which have been set up since without regard to the Code, should be "validated" by later workers in the same area, with due respect to the principles set out in Articles 13, 14, 15 and 36.'

The Convenor of the Australian Stratigraphic Committee advised as follows (pers. comm. Dr N. H. Fisher, 15 Dec. 1971):

'To the extent that Eyrian was used as a stratigraphic name before the Australian Code of Stratigraphic Nomenclature was adopted, the name Eyrian, and its correct form under the Code—Eyre, must be regarded as preempted. The name can only be used as a stratigraphic name in the sense in which it was first used in the literature or in the sense in which it was most widely accepted at the time the Code was adopted. Redefinition of the unit to which the name was applied is permissible (and desirable) in the light of new and more precise data, provided the first-given or most widely accepted sense is not significantly departed from.'

Those who may query the application of a rock stratigraphic name over such a large area as we propose to do here are referred to 'Summary of International Guide to Stratigraphic Classification, Terminology and Usage —ISSC Report 7b' (Hedberg, 1972, p. 303) which suggests: 'The extent of lithostratigraphic units is controlled entirely by the continuity and extent of their original definitive lithologic features'. We shall try to demonstrate that such 'continuity of definite lithologic features' does indeed exist.

For this purpose, and to eliminate, as much as possible, future causes for misunderstandings, we propose to adopt the following procedure. Firstly, the whole southwestern portion of the Great Artesian Basin over which the Eyre Formation is distributed will be divided into specifically designated areas. Within each area a typical section will be defined and described in detail. As it is necessary to identify one specific type section for the total region and for the designation of the stratigraphic name, the section situated 4.8 km east of Innamincka homestead is chosen as the TYPE SECTION. (Figs 2 to 8). All other sections are regarded as supplementary sections, typical for their respective areas. This procedure will also permit further reference sections to be added as new data become available.

Correlation between the various type areas is based primarily on lithological criteria, supported by extensive palynological evidence. The terminology applied to late Cretaceous and early Tertiary sediments in parts adjacent to South Australia must also be discussed to clear up certain misconceptions and miscorrelations in southwestern Queensland.

DERIVATION AND USAGE OF NAME

The name Eyre is derived from Lake Eyre, the largest of all Australian playa lakes, which lies at the centre of the area under discussion. Lake Eyre, the dry, salt-encrusted floor of which extends to 15 m below sea level, is also the lowest part of the Australian continent and thus forms the focus of a very large endoreic drainage system, encompassing about 1 280 000 km^2. The western and southern margins of the drainage system also delineate the approximate limits of application of the term Eyre Formation.

Since the validity and redefinition of the term Eyre could be controversial, the derivation and past usage of the name are reviewed in detail.

Woolnough & David (1926, p. 340) first used the name 'Eyrian Series' alongside a stratigraphic column at Muloowurtina (South Australia). Their only other mention of the name is on the legend of the geological map of northeastern South Australia (pl. 22) and the section from Mount Babbage to Lake Callabonna (pl. 23). The 'Eyrian Series' is shown as Tertiary and is decribed as sandy shale (p. 240) equated to mesas of 'Desert Sandstone' (pl. 22) and 'sandstone and shale' (pl. 23). The occasional occurrence of fossil leaves of *Banksia* and *Eucalyptus* is mentioned.

The next and most definitive use of the term 'Eyrian Series' was by R. L. Jack (1930), who recognized the unconformable relationship between the unit and the Winton Formation in a number of places and also showed the distribution of 'Eyrian Series' in several cross-sections through the Great Artesian Basin, leaving no doubt about the application of this stratigraphic unit (Jack, op. cit., pls. 2 and 3).

David (1932, p. 88) used the name again: 'The only strata which are possibly Eocene are those of the Eyrian Series, occurring in Queensland and South Australia . . .'

Kenny (1934, p. 85) subsequently extended the application of the name into northwestern New South Wales, 'following the practice adopted by Dr R. L. Jack in South Australia . . .'

The name Eyrian was clearly used by Jack (1930) and Kenny (1934) as a lithostratigraphic term, as was pointed out by Singleton (1941) when he suggested that Woolnough & David (1926) 'did not intend to propose a stage name, but only to name a local (even though widespread) series'. The closest to what might be regarded as a designation of a type area and type section is found in David & Browne (1950, p. 543): 'This series, so named from its occurrence round Lake Eyre, covers a considerable area of the Great Artesian Basin and includes much that was formerly called Desert Sandstone—The sequence of conglomerates, grits, sandstones and shales with beds of lignite, and occasional masses of granitic debris . . .' This preceded the description of a measured section quoted as 335 ft thick 'near Cordillo Downs', and a brief discussion of the distribution of the unit in South Australia, Queensland, and New South Wales.

Unfortunately the exact location of the measured section near Cordillo Downs is not given, otherwise this would have been the obvious choice for the type section. Although the senior author has measured a number of Tertiary sections around the Cordillo region, he feels that the exposures near Innamincka are more easily accessible and perhaps more representative of the overall lithology of the Eyre Formation. The Innamincka Section is therefore designated the type section for the whole southwestern portion of the Great Artesian Basin.

Whitehouse, who had used the term in 1940, changed the form of the name in 1954 to Eyrian Formation, again referring to sections in adjoining parts of South Australia—apparently in an attempt to conform to the Stratigraphic Code.

After that the name fell into disuse. The key to the sudden aversion to the name is to be found in the cross-section of Woolnough & David (1926, table 23) from Mount Babbage to Lake Callabonna, on which a thin veneer of Eyrian rocks is shown to cap Mount Babbage.

In 1955 Woodard found some plant fossils on Mount Babbage, and Glaessner & Rao (1955) showed conclusively that the sediments capping Mount Babbage were not of Tertiary but of early Cretaceous to late Jurassic age. Subsequently it was argued that since Mount Babbage was shown as being formed of sediments of the Eyrian Series and since this had been proved to be incorrect, the term Eyrian series was no longer a valid name. However, the argument would be valid only if Mount Babbage had been designated the type section or had been given some other specific significance. Close study of Woolnough & David (1926) makes it clear that these authors attached no special significance to the Mount Babbage locality. The description in the text relates solely to the exposures 'south of McGilp's homestead at Muloowurtina Station' without mention of Mount Babbage; so Mount Babbage is only a part of a cross-section wrongly identified.

Although the arguments against the term Eyre were carried by word of mouth they persuaded workers in the Great Artesian Basin to avoid the established name Eyre and to introduce new formation names (Forbes, 1966; Freytag *et al.*, 1967).

The history and usage of the name Eyre show clearly that it was meant to identify the early Tertiary sequences of clastic rocks of the western Great Artesian Basin. We conclude therefore that the name Eyre is a valid name

for a stratigraphic unit, which we define in this paper. Other proposed names such as Murnpeowie Formation (Forbes, 1966) and Macumba Sandstone (Freytag *et al.*, 1967) are abandoned.

Owing to an oversight and erroneous advice by the Central Registry, Williams & Polach (1967) used the name Eyre in the form 'Eyre Gravel' for terrace sediments in the Lake Torrens Region. As priority of usage and application is undoubted we suggest, and Dr Williams agrees, that this application of the name be abandoned.

Finally it should be noted that one derivative of Eyre, used in the form Eyrean subregion, was proposed by Spencer (1896) to identify a specific zoological province. However, as this name refers solely to a modern faunal assemblage (and is spelt differently) we see no possibility of confusion with the stratigraphic name Eyre Formation.

GENERAL DEFINITION

The Eyre Formation is defined here as that sediment sequence of early Tertiary age, consisting primarily of mature quartz sandstone with interbeds of clay, carbonaceous shale, and lignite, which unconformably overlies the Cretaceous sediments of the Neales River Group (Wopfner *et al.*, 1970) or older sediments of the Great Artesian Basin (e.g. Algebuckina Sandstone and equivalents).

The overall lithological features which characterize the Eyre Formation over a very large area are: great maturity of the sandstone and conglomerate, a high polish of the clastic components from medium sand grains to pebble size, generally low sphericity, good to excellent sorting of the sands, and upwards-fining sequences with large-scale current-bedding in the basal coarse-grained beds and festoon bedding or current lamination in the finer-grained beds. Rock types and local variations will be dealt with in detail in the description of the type section and reference sections.

The formation may contain a disconformity, at least along the southern margin of the Great Artesian Basin (see Biostratigraphy). As the contact cannot be mapped either lithologically or by petrophysical means, and as the Eocene sediments have obvious affinities with those of the Paleocene, the whole sequence is considered as one rock unit of Formation status.

In the subsurface the top of the Eyre Formation is identified by the contact with the overlying carbonate sequence of the Etadunna Formation or its equivalents. This contact is either a disconformity or an unconformity and is marked in places by a ferruginous oolite or pisolite, as in the Lake Eyre bores (Johns & Ludbrook, 1963). In some places the top of the Eyre Formation may be affected by incipient silicification. Both the upper and lower boundaries exhibit marked changes in response-character on petrophysical logs (see Figs. 9, 15, & 16).

In surface exposures the top of the Eyre Formation is marked by a palaeosol composed of a deep chemical weathering profile and capped by a quartz silcrete here referred to as silcrete of the Cordillo surface. This silcrete, which typically forms polygonal columns, is overlain either disconformably or unconformably by ferruginous pisolite (Wopfner, 1960; Wopfner & Twidale, 1967) now termed the Doonbarra Formation, which will be described separately (Wopfner, in press).

TYPE SECTION AND AREAS

The Eyre Formation will be defined by describing one type section near Innamincka and a number of reference sections. The lithological sequence of each section is regarded as diagnostic for specific areas, all of which together constitute the area of distribution of the Eyre Formation.

Although morphological features and particularly structural characteristics were considered in the selection of these areas, one should not expect them to be delineated by sharp boundaries. In fact any such boundary can only be an arbitrary and artificial line of demarcation; otherwise, the argument for a single stratigraphic name would be invalid.

The type areas should therefore be regarded as flexible and convenient subdivisions to which new ones may be added as more information becomes available. The type areas together with their relevant sections are tabulated in Table I. The locations of the type and reference sections are shown in Figures 1 and 8.

Initials after each section heading indicate the principal contributor of that section.

No specific section has been identified in the Southwestern Tablelands. However, the widespread distribution of highly polished conglomerate containing typically lower Tertiary

TABLE I

Type areas and corresponding sections

Type area	Section name and location
Central Fold Belt	
Surface anticlines along Innamincka and Cordillo structural trends and continuation into Queensland (Durham, Beetoota, Curalle, Morney structures). Also included is Sturt's Stony Desert.	Innamincka (4.8 km E of Innamincka hstd). Lat. 27° 42'18"S, Long. 140° 48'00"E. (Type section)
Strzelecki Desert	
(North of Yandama Creek). Area overlying Cooper Basin and Naryilco Shelf.	Moomba (Delhi-Santos well Moomba No. 4). Lat. 28° 12'56"S, Long. 140° 15'06"E.
Southern Tablelands	
Southern margin of Great Artesian Basin between Adelaide Geosyncline and Lake Blanche-Clayton trend.	Reedy Springs (3.2 km NW of Blanchewater ruins). Lat. 29° 31'46"S, Long. 139° 25'47"E.
Frome Embayment	
Region between Flinders Ranges, Barrier Ranges, and Tibooburra High.	Lake Callabonna (MINAD exploration well Lake Callabonna No 1A). Lat. 30° 05'13"S, Long. 139° 56'50"E.
Lake Eyre Region	
Lake Eyre depression, Tirari Desert, and southern Simpson Desert.	Lake Eyre, S. Aust. Dep. Mines bore Lake Eyre 20 (in Madigan Gulf, 32 km from shore). Lat. 28° 48'00"S, Long. 137° 30'20"E.
Western Tableland	
Oodnadatta region and stony tablelands between western Simpson Desert (Finke River Flats) and Western margin of Great Artesian Basin.	Mt Alexander (57 km NNE of Oodnadatta). Lat. 27° 05'54"S, Long. 135° 42'06"E.
Southwestern Tableland	
Area south of Coober Pedy and southwest of Margaret Creek.	No section measured.

floras (e.g. Offler, 1969) and micro-floras (see Biostratigraphy) justifies the inclusion of this area in the discussion. A reference section will have to be established later.

Detailed descriptions of the various sections are available on open file at the Geological Survey of South Australia (*Geol. Surv. S. Aust. Rep. Book* 73/89).

CENTRAL FOLD BELT (H.W.)

The Central Fold Belt encompasses the Innamincka and Cordillo structural trends in the central Eromanga Basin and their extensions into Queensland. In the south the area is underlain by the Permian Cooper Basin and the surface structures follow the same northeasterly trend as the deeply buried Permian anticlines. It will be shown that the Tertiary structures may owe their similar axial trends to rejuvenations of movements along similar zones to those which caused the deformation of the Permian.

The Tertiary structures form large, elongated, usually closed anticlines, commonly arranged *en echelon* (Wopfner, 1960). Limb

dips of the domes range from less than 1° to more than 20°. Their crests have invariably been breached and cut back by scarp-foot erosion, leaving pronounced cuestas to mark the limbs of the anticlines. The cuestas and escarpments provide the best exposures of the formation. The formation rests disconformably or with low-angle unconformity (e.g. Morney Dome, Wopfner, 1960) on sediments of the Cenomanian Winton Formation.

Type Section. The type section is about 4.8 km east of Innamincka homestead on the northern bank of Cooper Creek (Fig. 2), where some 40 m of Eyre Formation is exposed in the south face of a small bluff and at the west face of a silcrete-capped spur (Figs. 3 and 4).

The contact with the underlying Winton Formation, consisting here of fine-grained kaolinitic and feldspathic sandstone, is well exposed. Although overall the contact is fairly planar, dipping about 2°SE, in detail many scour structures and other erosional features can be observed (Fig. 5).
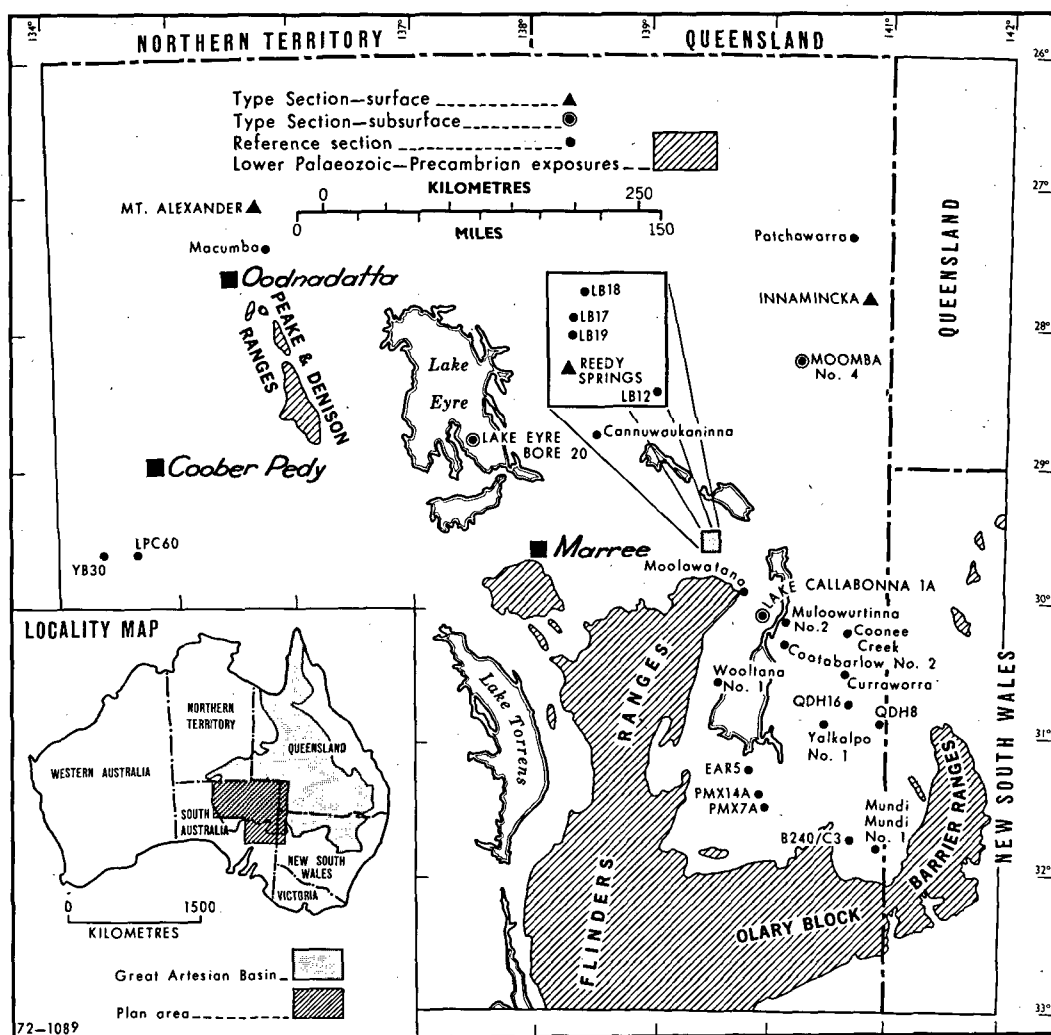
Fig. 1. Map of study-area, showing type and reference sections and palynological sample-points.

The basal unit of the Eyre Formation is a pebble conglomerate, which, although only a few decimetres thick in the type section, is of such characteristic composition and appearance that it forms an infallible marker horizon over many thousands of square kilometres. It is very mature and shows a marked bimodality as demonstrated by curve H.W. 256 in Figure 6. The pebble-size components consist, in order of abundance, of grey and milky quartz, red jasper, usually amber coloured agate, and black or brown silicified wood. The quartz and jasper pebbles are usually well rounded but of low sphericity, commonly discoidal or ellipsoid. The fossil wood pebbles are well rounded

but less perfect than the quartz, and the agate less so again (Fig. 7). The agate pebbles are commonly pitted.

The finer fractions, from granule size down, are generally subround to subangular and consist predominantly of quartz.

As the cumulative curve of sample H.W. 256 shows (Fig. 6), there is also about 5 percent of very fine-grained 'tail' fraction. All grain surfaces, but particularly the pebble fraction, are highly polished. Commonly, the Eyre Formation manifests itself first by the presence of such highly polished pebbles. Not within the type section, but at many other places (e.g. eastern end of Callamurra waterhole),
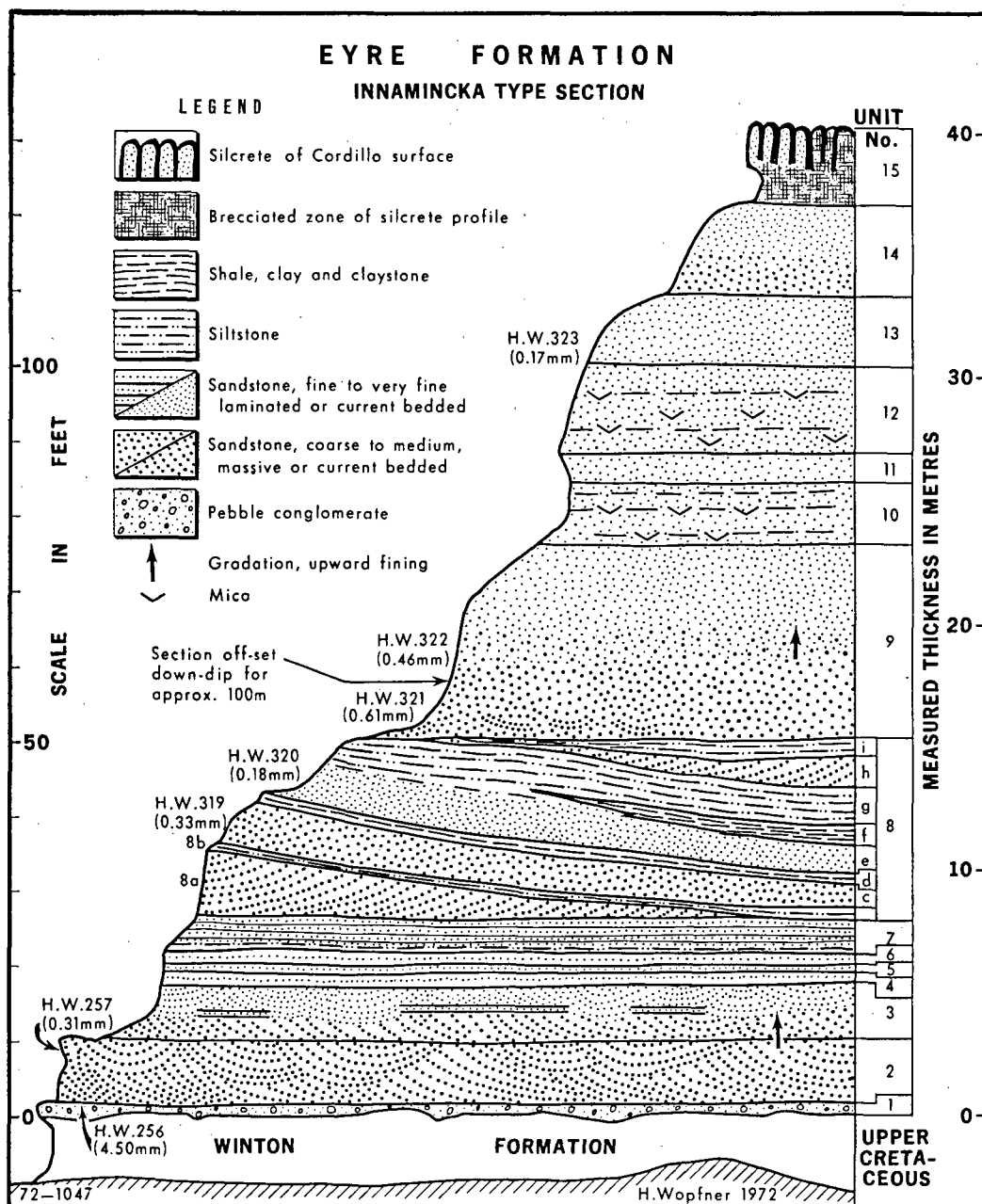
Fig. 2. Type section of Eyre Formation, 4.8 km east of Innamincka homestead. H.W. numbers refer to grainsize curves in Fig. 6. See Figs. 3 to 5 for photographs of section.

large trunks of fossil trees occur in the basal sands. They have a different texture from the wood pebbles and appear to have grown during the early Tertiary not far from their place of burial.

The basal conglomerate is overlain by a brown coarse-grained mature quartz sandstone. The sandstone shows large-scale current beds with tangential toe-sets, but some cut-and-fill structures are also present. A few kilometres

Fig. 3. Upper part of type section of Eyre Formation on Cooper Creek, 4.8 km east of Innamincka homestead. Arrow marks the base of unit 9 (see Fig. 2). The dark capping is formed by partly silicified sandstone. (Photo H. Wopfner).
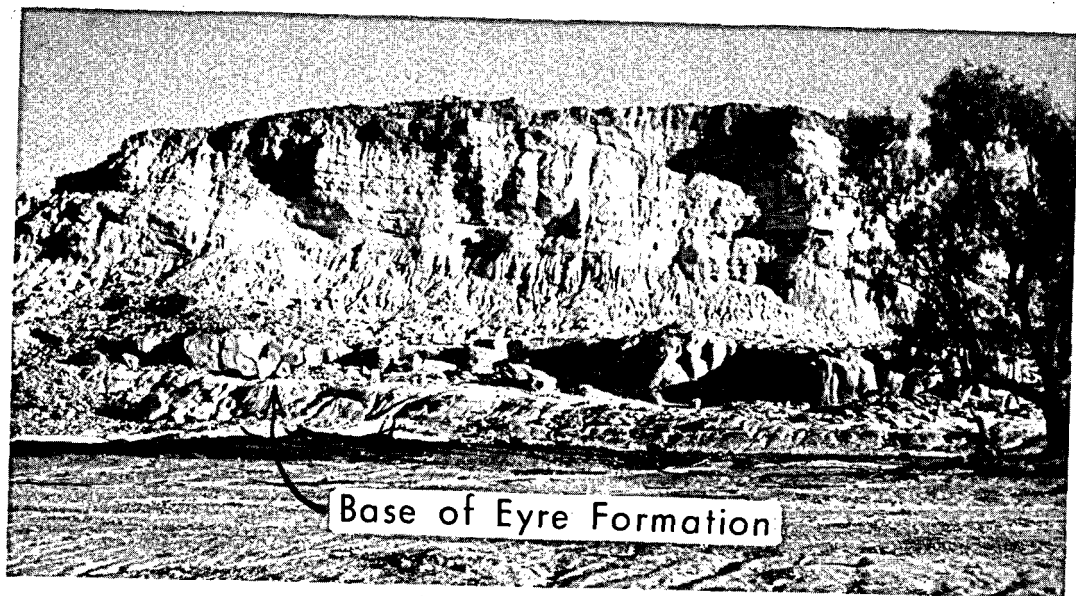

Base of Eyre Formation

Fig. 4. Lower part of type section of Eyre Formation on Cooper Creek, showing the planar, gently dipping contact with the Upper Cretaceous Winton Formation. The dark bed at the top of the exposure is unit 9. (Photo H. Wopfner).

Fig. 5. Small scale scour at the base of the Eyre Formation, Innamincka type section. The scour cuts into feldspathic and kaolinitic sandstone of the Winton Formation and is filled with polymictic basal conglomerate. Diameter of coin to the right of the scour is 2.5 cm. (Photo H. Wopfner).

to the east, at Callamurra waterhole, planar foresets may be observed at a corresponding level. In contrast to the basal conglomerate, the sandstone is very well sorted, as shown by curves H.W. 257 (Fig. 6). The sandstone (Unit 2) fines upwards into Unit 3 with corresponding diminishing current features. This is followed by some more fine-grained clastics (see Fig. 2). Generally the lower units appear to be more in the nature of sheet deposits.

Higher up, the sequence becomes more lenticular, as shown by the lenses and channel structure of Unit 8. The sandstone is very mature and very well sorted (curves H.W. 319 and 320), whereas the siltstone is kaolinitic. The clay lens (unit 8f) consists of about 44% crystalline kaolinite, the remainder being quartz with a little mica.

The upper part of the section (Fig. 3) consists essentially of mature well sorted sandstone, somewhat micaceous in places. Unit 9, a brick-red sandstone, shows even better than Units 2 and 3 an upwards fining due to varying energy (current) levels. The section is capped by the silcrete of the Cordillo surface. Some layers of incipient silicification at lower levels (Unit 14) are interpreted as short-lived periods of non-deposition during which the sediment was exposed to silicification processes.

Fossil Content and Age. No fossils have been detected within the type section; a few ill preserved plant impressions have been found on the southern limb of the Innamincka dome, near the Queensland border. A silicified tree trunk about 1.5 m long occurs in an equivalent of the lower sandstone units near the eastern end of Callamurra waterhole.

The only firm evidence of the age of the Eyre Formation in this region are some palynological dates on samples from the Patchawarra bore which indicate a Paleocene age (see Biostratigraphy).

Distribution. The most characteristic features of this area are the large surface structures which extend from Tickerna, south of Cooper Creek, to the Morney Dome in western Queensland. Erosion has led to the development of prominent cuestas, mesas, and tablelands, and the Eyre Formation is usually well exposed along the escarpments delineating these landforms. Invariably the formation, forming a continuous or near-continuous cap across the structures, can be followed down-dip until it disappears below the younger sediments in the synclines, as, for example, at the Innamincka Dome, the outline of which is clearly identified by a rim of exposure of Eyre Formation (see Fig. 8). Similar features on other struc-
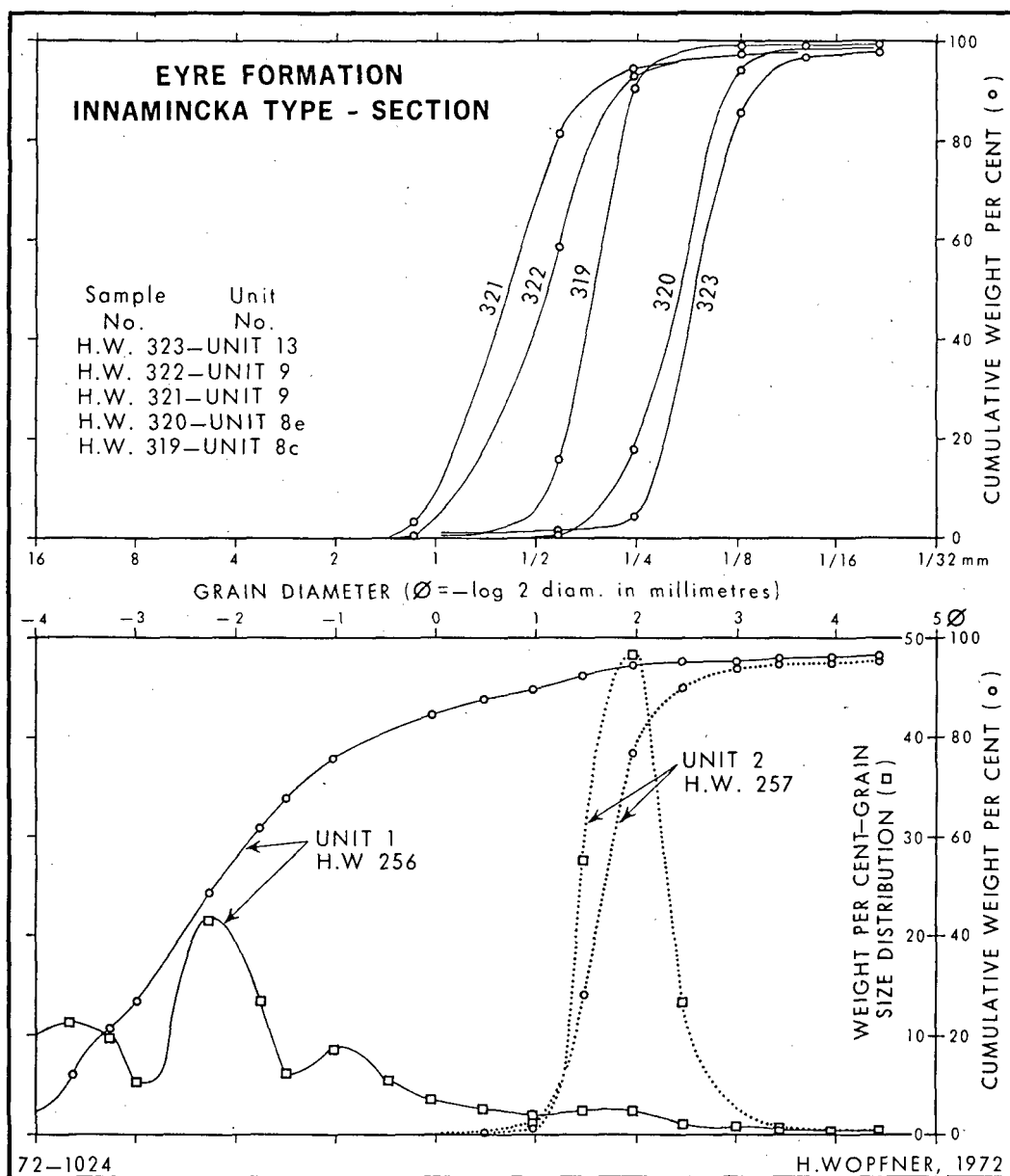
Fig. 6. Cumulative curves of sieve analyses of sands from the Innamincka type section. Note marked bimodality in basal unit and excellent sorting higher up the section.

tures have been described (Jack, 1925, 1930; Sprigg, 1958; Wopfner, 1960).

Although the records are not plentiful there appears to be sufficient subsurface evidence to suggest that the Eyre Formation forms a continuous blanket in the synclinal areas.

In these synclines, particularly down-dip from major incised streams, the basal sands carry subartesian water, the overlying shale and siltstone acting as an aquiclude. They can produce considerable amounts of slightly brackish water, quite suitable for stock purposes. For instance, a water well drilled on the Innamincka Dome just east of the Queensland border was capable of pumping more than 20 000 litres (5000 gallons) per hour, supply-
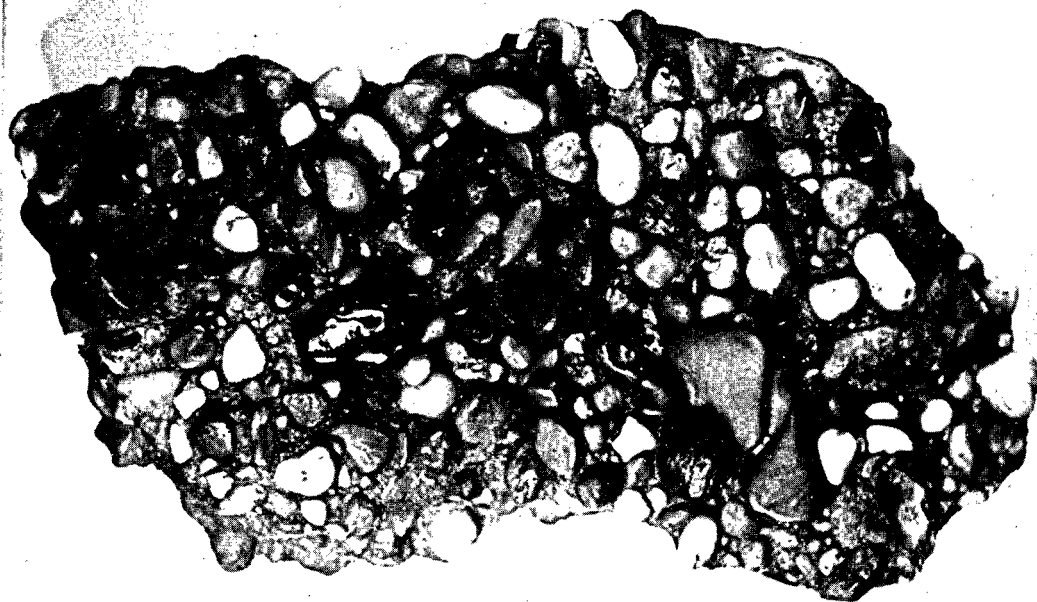
Fig. 7. Close up of basal conglomerate, southwest of old road crossing near Callamurra water hole. Note the good rounding but low sphericity and polymictic nature of the conglomerate comprising quartz, fossil wood, agate, and rock fragments. Length of specimen: 21 cm. (Photo H. Wopfner).

ing the entire drilling operation of Innamincka No. 1 with water.

West of the Innamincka and Cordillo structures the Eyre Formation is largely covered by the younger sediments of Sturt's Stony Desert. It appears as a few low outcrops in the westernmost part of the Cordillo 1:250 000 Sheet area and is known in subsurface from a few water-bores. In the northern part of Sturt's Stony Desert near the Queensland border the formation remains subsurface, and extends below the Simpson Desert. In the Birdsville town bore it is 64 m thick, the base being 15 m below sea level.

During recent drilling by the Bureau of Mineral Resources east of Goyders Lagoon in the southeast corner of the Pandie Pandie and the northeast corner of the Gason 1:250 000 Sheet areas the Eyre Formation appeared at shallow depths. According to Mond (1972) the formation averages about 30 m thick and its top is 3 to 4 m below surface level. The base can usually be readily identified by the marked decrease in radioactivity on the

gamma-ray log. Farther south and southwest the base of the formation rises again in the Mount Gason Anticline, where it is widely exposed along the escarpments and table-top hills.

The thickness of the Eyre Formation is strongly influenced by structure. The formation is thickest in the synclines, about 90 to 120 m, but thins rapidly near the crests of the anticlines. Thinning on the Innamincka Dome is demonstrated by the sections in Figure 8, which show that the Eyre Formation is less than 1 m thick near the crest of the dome. Similar thinning may also be observed on the Curalle, Betoota, and Morney Domes (Wopfner, 1960). On the Morney Dome the formation actually wedges out completely across the culmination of the dome.

Lensing of individual units and up-dip reduction of numbers of units suggest that the thinning is due to sedimentary onlap. However, a certain amount of reduction by post-depositional erosion of the crests of the structures is also suspected.
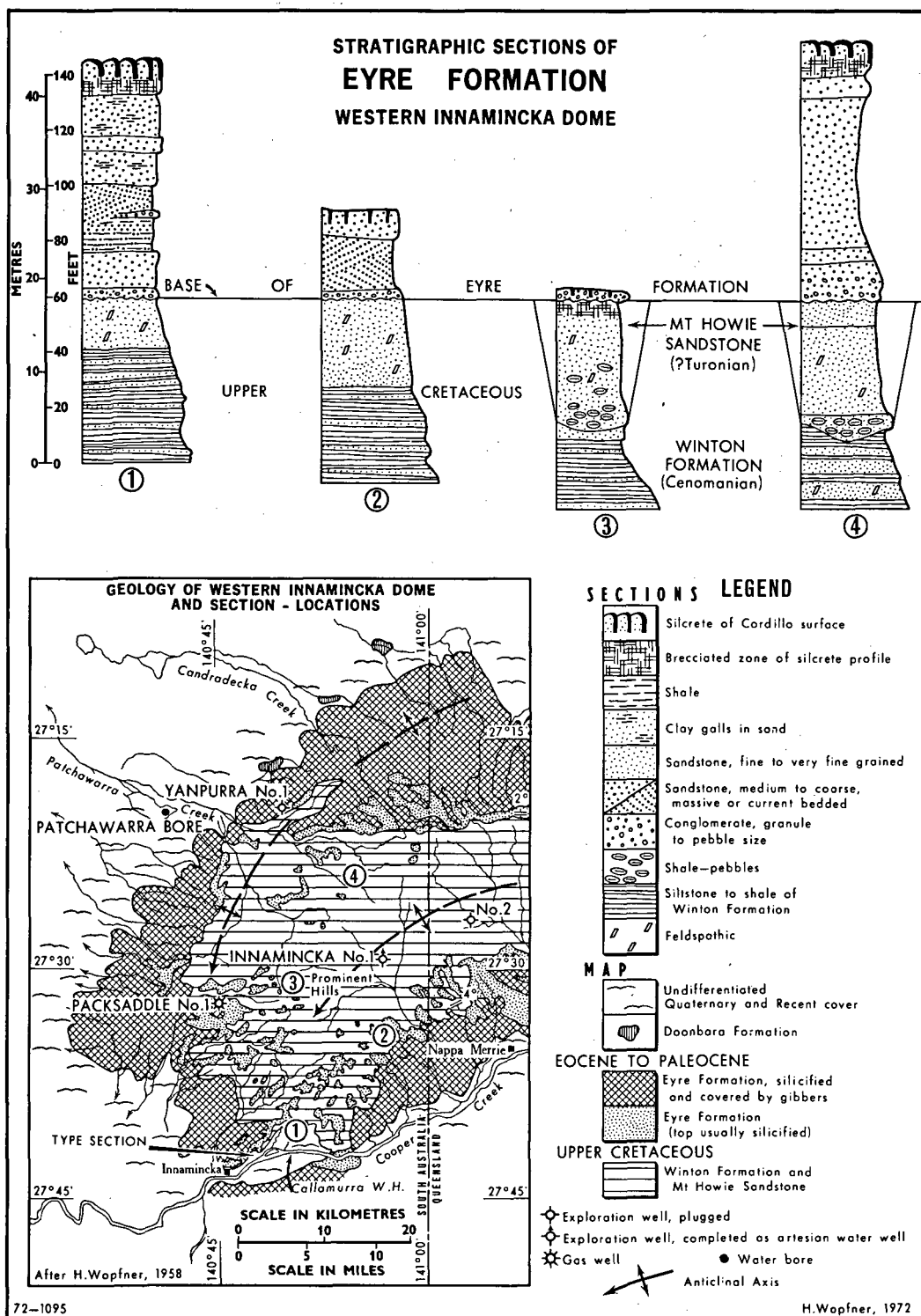
Fig. 8. Development of Eyre Formation across the Innamincka Dome, showing thinning across anti-
clinal crest and superposition on channels of Mt Howie Sandstone. Generalized geological map
of Western Innamincka Dome shows section distribution of Eyre Formation.

STRZELECKI DESERT (H.W.)

The northern and northwestern boundary of the Strzelecki Desert area is formed by the course of Cooper Creek downstream to the west from its junction with the Wilson River. To the southwest an alignment of playas, comprising lakes Kopperamanna, Killamperpunna, Gregory, Blanche, and Callabonna, and termed the Lake Blanche Lineament (Wopfner & Cornish, 1967), bounds the area. Yandama Creek is taken as the southern limit and the Tibooburra High forms a natural border on the east. Except for the exposures near the Tibooburra High and a few low outcrops near the tristate corner (Wopfner & Cornish, op. cit.) and along Yandama Creek, the Eyre Formation in this area is known only from drilling information. However, as the region is underlain by the hydrocarbon province of the Permian Cooper Basin (Wopfner, 1966; Kapel, 1966), there are enough exploration wells to demonstrate the ubiquity of the Eyre Formation in the subsurface.

Typical Section. Delhi-Santos Moomba No. 4 well was selected as the typical section. Good drill cuttings were obtained from the near-surface section, including the Eyre Formation, for special studies (Townsend, 1967). Furthermore, electric and gamma-ray logs were run over this interval, whereas normally the near-surface sections are only covered by gamma-ray log.

The Eyre Formation in Moomba No. 4 rests on late Cretaceous Winton Formation and the contact between them can be recognized readily on the petrophysical logs, as shown in Figure 9. The contact, at 256 m below sea level, is thought to be disconformable, although a very low-angle regional unconformity may be inferred towards the southeastern margin of the area, where the Eyre Formation rests on progressively older rocks.

Figure 9 shows that the Eyre Formation in Moomba No. 4 may be subdivided roughly into three major lithological units: a basal sandstone unit, a coal-siltstone sequence, and a siltstone-arenite sequence at the top.

The basal 3 m consists of grey medium to coarse mature quartz sandstone with some granule-size components. It shows a slight bimodality; although the grains are sub-rounded many are pitted. The typical basal conglomerate, composed of pebbles of fossil wood, agate, and red jasper, is apparently absent. The overlying sandstone is medium-grained, well sorted, and very similar to Units 2 and 3 in the Innamincka type section. An upwards fining is apparent. The composition is primarily quartz with small amounts of mica. The sand is in parts weakly cemented with calcareous matrix and, in parts, friable.

The middle of the sequence contains numerous seams of lignitic coal and carbonaceous clay with interbeds of generally fine-grained clastics. The lignitic coal is dark brown, low-grade, with abundant wood fragments and other plant material. According to W. K. Harris (Palynological Report 3/67 unpubl.) residues from the lignite 'consisted mainly of cuticular woody fragments, with very few palynomorphs, possibly indicating the presence of autochthonous lignite dominated by wood and leaf material with little inorganic detritus. The environment could be considered as paludal'. Interbeds consist of green slightly dolomitic siltstone, dark grey clay, and some fine-grained loose sand (Fig. 9).

The upper unit consists substantially of arenite, with a coarse to medium well sorted sandstone grading upwards into finer-grained kaolinitic arenite.

The total thickness of the Eyre Formation in Moomba No. 4 is 89.3 m. The top is marked by a change from the dominant sandstone deposition to a sequence of chalky carbonate and calcareous and dolomitic shale. This change in overall lithology is also well shown by the character change of the curves of the various petrophysical logs, particularly the electric logs (Fig. 9).

The carbonate sequence above the Eyre Formation at 203.3 m is correlated with some confidence with the Etadunna Formation of the Lake Eyre region (Stirton et al., 1961; Johns & Ludbrook, 1963; Wopfner & Twidale, 1967).

Fossil content and age. Lignitic samples from 253 m (S1391) and 262.1 m (S1392) yielded a Paleocene microflora (see Biostratigraphy).

Some impressions of lanceolate leaves resembling *Eucalyptus* were observed in a dark grey clay recovered from a seismic shot-hole east of Yandama bore.

Distribution. The Eyre Formation has been encountered in over 100 oil exploration wells drilled within the Cooper Basin and also in many water-bores, and it can be stated confidently that it forms a continuous sedimentary blanket over the whole of the Strzelecki
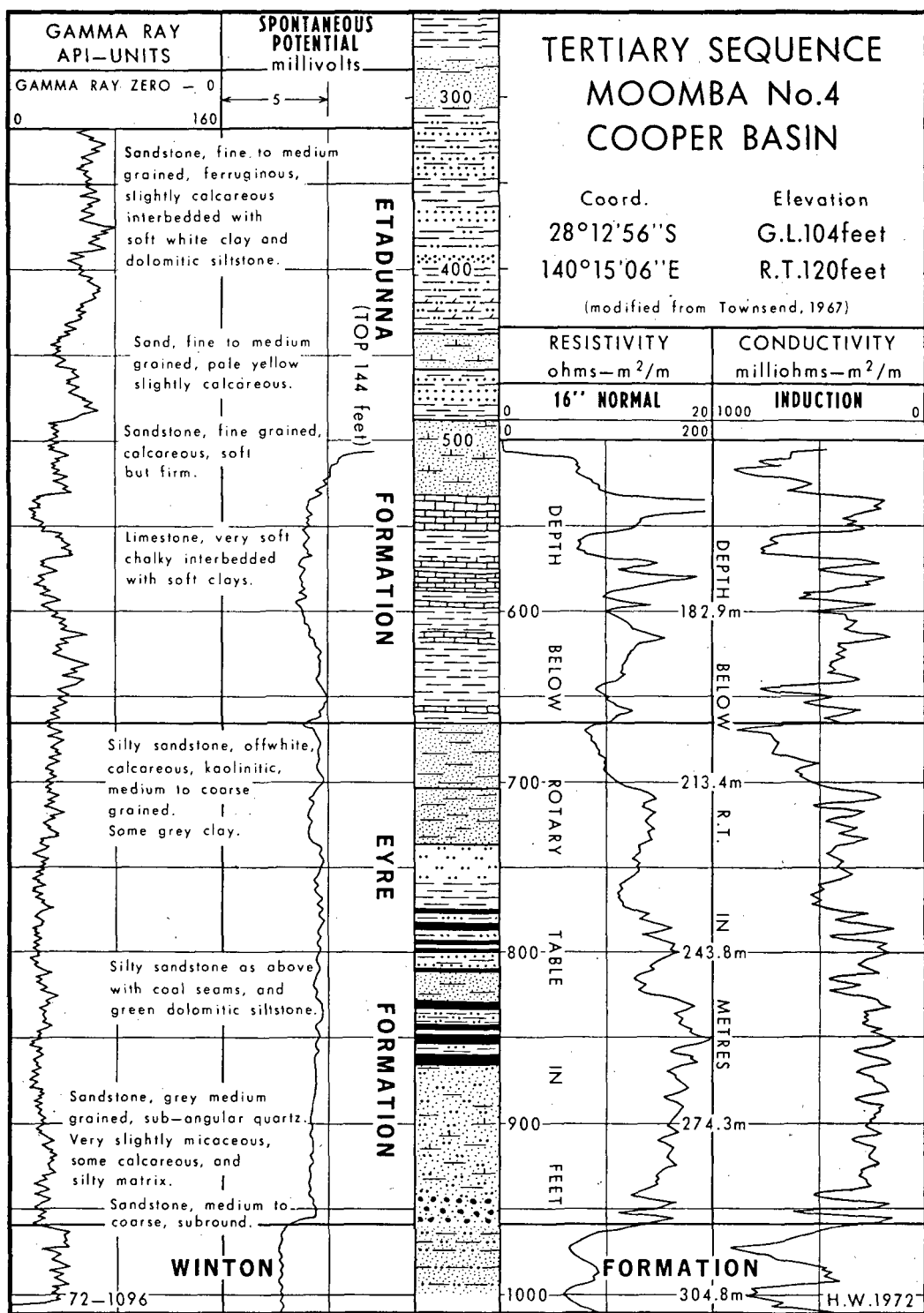
Fig. 9. Composite log of near-surface section in Delhi-Santos Well Moomba No. 4. The interval of the Eyre Formation is marked by the petrophysical log-characteristics.

Desert, merging to the south with equally continuous occurrences in the Frome Embayment.

Although the typical basal conglomerate appears to be absent in the section in Moomba No. 4, it is known from several wells and water-bores, particularly along the Queensland border and around the tristate corner,

whence it appears to be continuous to the outcrop sections along the western margin of the Tibooburra Basement High (Fig. 10). Here, conglomerate of typical composition is well exposed sporadically from north of Pincally to the Tibooburra/Fort Grey road. A particularly fine example may be seen about 29 km north of Pincally homestead (southwest of
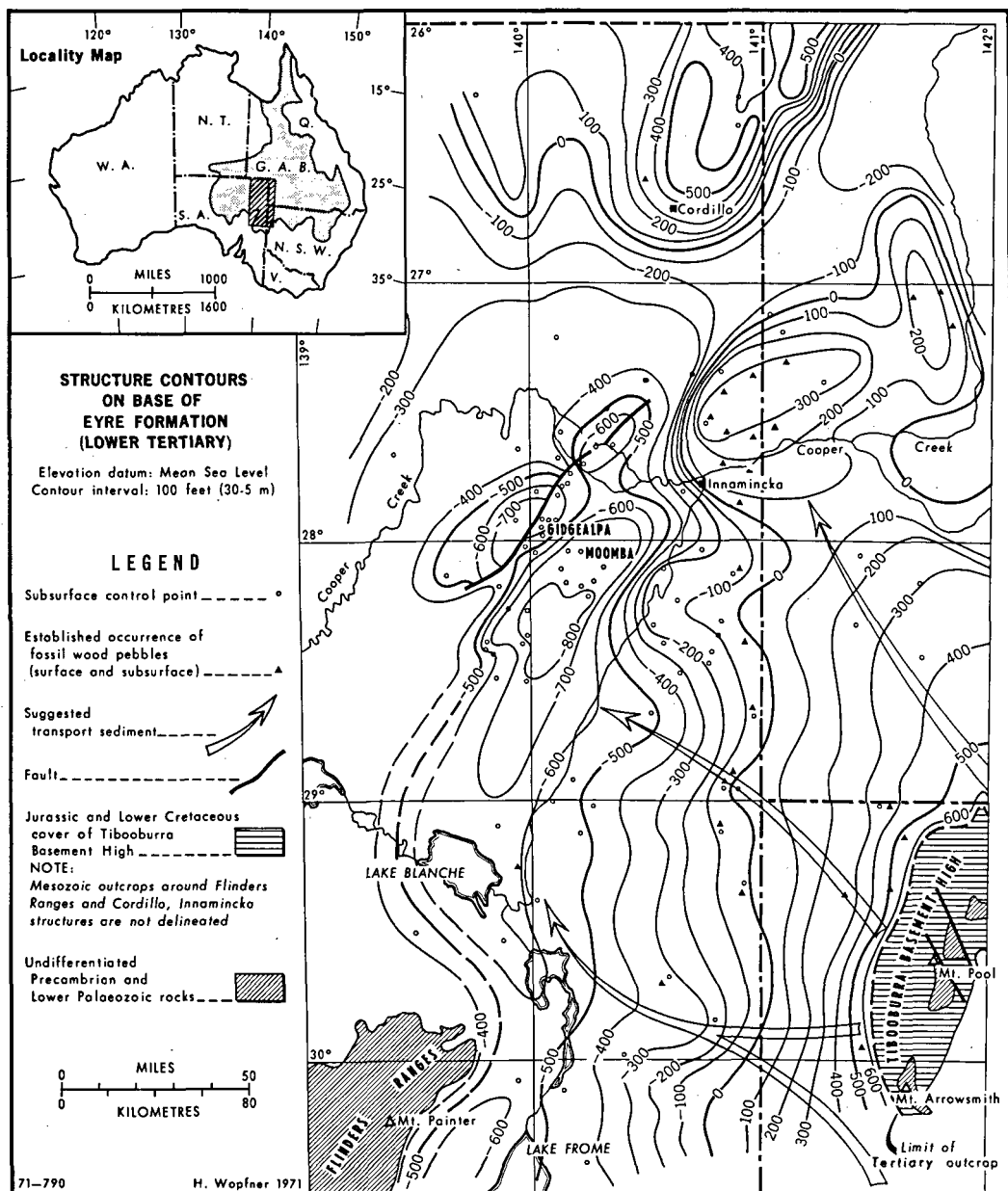

Fig. 10. Structure contour map of base of Eyre Formation in Strzelecki Desert region, showing close agreement with deep Permian structures of Cooper Basin.

Mount Pool), where about 15 m of Eyre Formation consisting of fossil wood conglomerate, kaolinitic sandstone, and pale green shale is exposed at the base of some low mesas.

The base of the Eyre Formation can usually be identified without difficulty by the marked reduction in radioactive response on the gamma-ray log. Information obtained in this way from petroleum exploration wells drilled to the end of 1971 was combined with waterbore data and outcrop information (Fig. 10) in an attempt to construct a structural contour map of the base of the Eyre Formation. Although the contours show a general similarity with the trends of young surface structures, a much more significant feature appears to be the overall conformity with certain structural features of the Permian Cooper Basin. This is particularly evident along the Gidgealpa-Merrimelia fault trend, which is a well established Permian trend: the same fault trend is also discernible on the Tertiary structure map. Similarly the Moomba depression is well represented by the deepest depression of the basal Tertiary surface. From the Moomba depression the contours gradually shallow towards the Tibooburra Basement High without any apparent similarity to Permian structure. A salient extending from the northernmost point of the Tibooburra Basement High northwestwards towards Innamincka appears to reflect the configuration of the late Palaeozoic structural surface.

Although the information used for this first attempt is insufficient to draw definite conclusions it appears that Tertiary movements not only followed similar trends to those established in the Permian, but that they also had the same sense: depressions were deepened, highs were accentuated.

The thickness of the Eyre Formation varies from about 60 to 140 m. Thickness distribution was not studied systematically, but casual observation appears to indicate similar tendencies to those observed in the outcrop areas of the Central Fold Belt, i.e. thinning across anticlines.

The facies development is fairly uniform within the central part of the area and the overall threefold lithological subdivision in the section in Moomba No. 4 can generally be recognized. Towards the southeast the sections become more sandy and somewhat coarser; lignite and carbonaceous clay

are still present in the water-bores around Bollards Lagoon near the tristate corner, but much thinner, constituting only about 15 to 20 per cent of the total section. In Fortville No. 3, 16 km southwest of the tristate corner, the total 120 m of Eyre Formation consists entirely of sand (Wopfner & Cornish, 1967).

These features indicate a source area to the southeast, and this is shown schematically by the arrows on Figure 10. A more detailed discussion of the aspect is attempted under Depositional Environment.

SOUTHERN TABLELAND (R.C.)

The Southern Tableland comprises the southern part of the Great Artesian Basin which extends from the northern margin of the Flinders Ranges to the Lake Blanche Lineament (of Wopfner & Cornish, 1967). The western boundary is formed by the Birdsville track high (Dulkaninna Structure), and to the south a subsurface 'high' extending northeast from the Mount Painter Block is taken as the boundary between the area of the Southern Tableland and the Frome Embayment.

Typical Section. The section at Reedy Springs (Figs. 11 and 12) 3.2 km northwest of the ruins of the old Blanchewater homestead, is the typical section for the area. It was described previously by Forbes (1966) as the type section of the 'Murnpeowie Formation'. A portion of the outcrop originally included by Forbes in the definition of the 'Murnpeowie Formation' has been excluded here as it appears to be separated by a fault from the main part of the section (Fig. 12).

The typical lithology is a submature to mature quartz arenite (in the terminology of Folk *et al.*, 1970) with interbeds of siltstone. The exposed rocks in the typical section are mostly bleached and secondarily calcified, ferruginized, and silicified. The light colours contrast with the darker hues of the fresh sediments in subsurface samples. Sorting in the sands (estimated visually) is good to moderate. The grains are subangular to rounded, polished, and of rather irregular shapes. The sands are commonly bimodal in the basal coarse-grained beds; the coarse fraction ranges from very coarse-grained to small pebble size, and grains are highly polished. Milky, clear, and grey quartz grains, black chert, and rare volcanics, jasper, and agate are present, and commonest in the lowest part of

the sequence. Silicified wood pebbles have been reported, and carbonaceous wood fragments are common in subsurface. The upper, finer-grained beds are generally well sorted, less polished, and more angular. The detailed lithology is given in Figure 11.

Bedding ranges from thick plane beds to laminations. Cross-bedding is common, consisting generally of planar foresets with angular toesets. Complex trough cross-stratification occurs in the central portion of the Reedy Springs sequence. Ripple marks (Fig. 13) and large-scale current bedding with both angular and asymptotic toesets are particularly well exposed at Blanchewater Hill, 2 km south of Reedy Springs and on the Strzelecki Track. Grooved surfaces, obliquely cutting planar current beds (Fig. 14), in the same area are interpreted by Wopfner either as friction-grooves or as slippage planes, caused by the slumping of an overlying sediment mass.

At Reedy Springs the Eyre Formation rests disconformably on Cenomanian Blanchewater Formation. The base is marked by scour structures commonly containing pebbles.

The top of the section is formed by a thick columnar silcrete which dips at 80° in conformity with the section. The relation of this to other silcrete is indicated in the cross-section (Fig. 12). The interpretation differs from that of Forbes (1966) in that a pre-folding and a post-folding silcrete are proposed.

Distribution. Within the Southern Tableland the Eyre Formation is largely restricted to erosional remnants which form isolated mesas and buttes, and isolated exposures extend into the Flinders Ranges. Along the margin of the Flinders Ranges the formation commonly dips steeply, having been tilted by drag along faults. A belt of steeply dipping exposures extends from south of Moolawatana in a wide sinuous trend to the Reedy Springs section (see map in Coats & Blissett, 1971; Forbes, 1966). From this fold belt the Eyre Formation descends to the north beneath the younger sediments of the Strzelecki Desert and is down-faulted to the east towards the Frome Embayment.

FROME EMBAYMENT (R.C.)

Within the Frome Embayment, the Eyre Formation occurs in two structural provinces; a basin west of Lake Frome with its axis close to the Flinders Ranges, and a gentle arch to the east over which the Eyre Formation thins
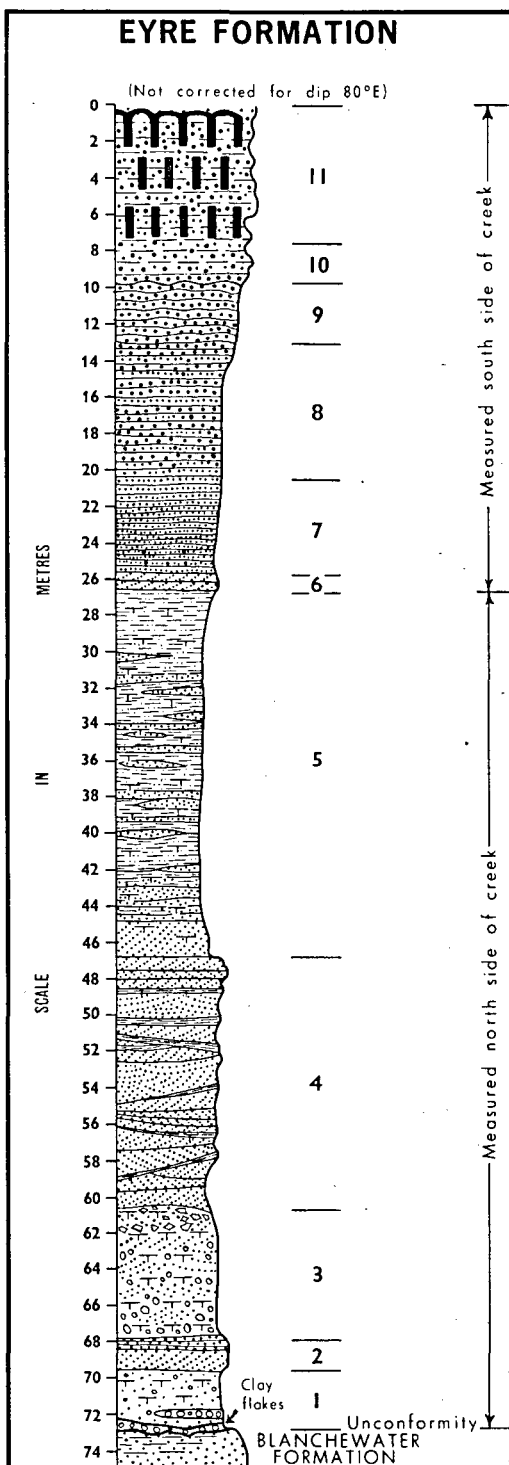

Fig. 11. Reedy Springs section. Both planar and cross-stratification are present.
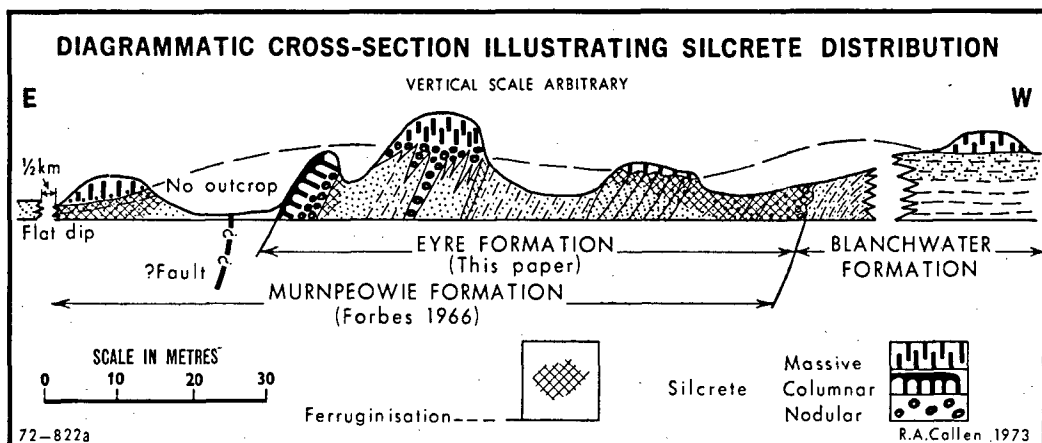
DIAGRAMMATIC CROSS-SECTION ILLUSTRATING SILCRETE DISTRIBUTION

VERTICAL SCALE ARBITRARY

E   W

½km

No outcrop

Flat dip

?Fault

EYRE FORMATION
(This paper)

BLANCHWATER
FORMATION

MURNPEOWIE FORMATION
(Forbes 1966)

SCALE IN METRES
0   10   20   30

Ferruginisation ___

Silcrete

Massive
Columnar
Nodular

72—822a   R.A.Callen .1973

Fig. 12. Generalized cross-section of Reedy Springs section showing relationship between Eyre Formation and now disused Murnpeowie Formation type sections. The relationship between pre- and post-folding silcrete is indicated. The post-folding silcrete does not contain columnar structure.
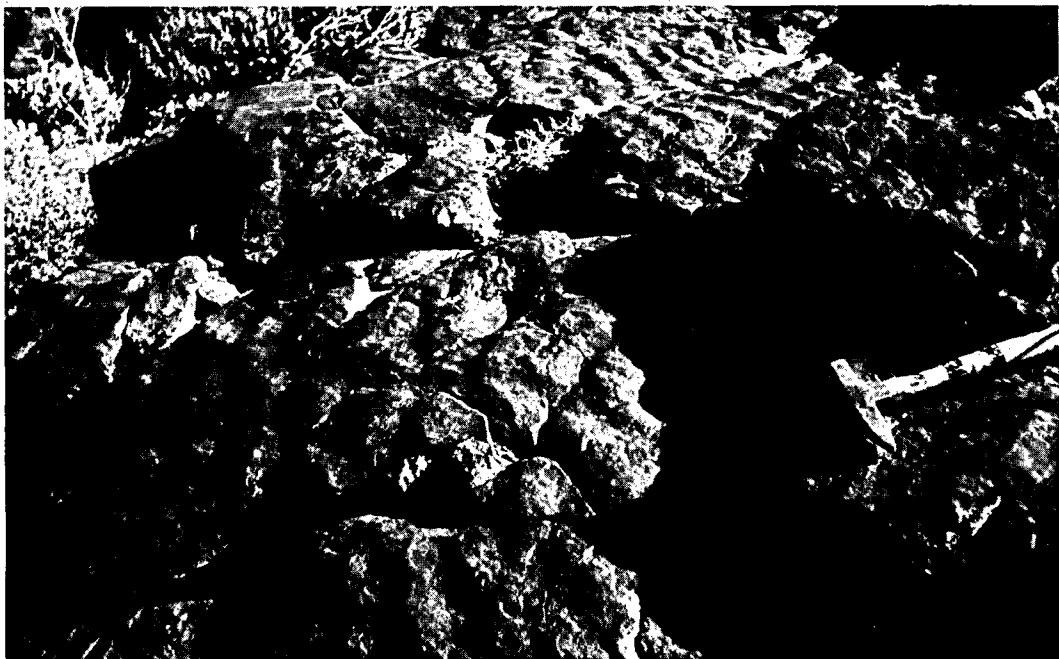
Fig. 13. Current ripple marks in sandstone of the Eyre Formation at Blanchewater Hill, 2 km south of Reedy Springs section. (Photo H. Wopfner).

by about half. The boundary between them runs about north-south through the centre of Lake Frome. The eastern limit of the eastern province is taken as the Barrier Ranges in New South Wales. The eastern province is complicated by a prominent high to the south in the Curnamona 1:250 000 Sheet area, flanked by a narrow trough to the east.

Lake Callabonna No. 1A (LC1A) exploration bore, drilled by Mines Administration Pty Ltd (Minad), is representative of the western basin and was selected as the typical
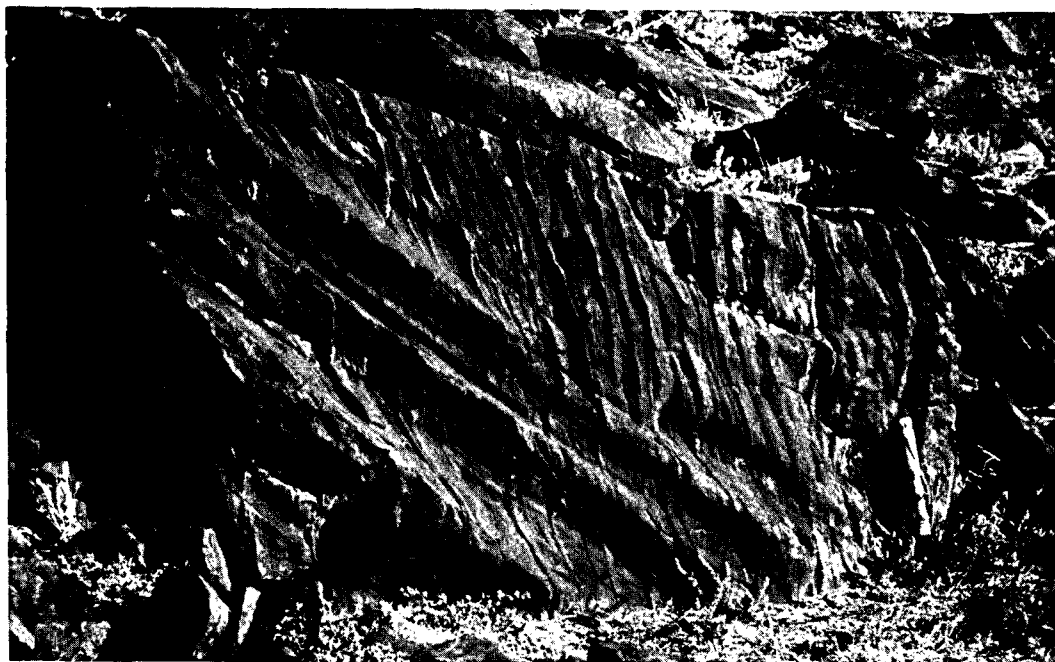
Fig. 14. Linear grooving cutting obliquely across planar forests of angular current beds. Exposure is on north slope of Blanchewater Hill adjacent to Strzelecki Track. (Photo H. Wopfner).

section for the Frome Embayment. Paleocene, Eocene, and Miocene microfloras obtained from the bore provide a useful time-framework for the rock units. Yalkalpo No. 1 stratigraphic well on the eastern edge of a structural high is selected as a reference section representative of the southeastern Frome Embayment (see Fig. 1 for well locations). The high is expressed at the Lower Cretaceous/Tertiary contact but its origin may well antedate the Cretaceous. At the Yalkalpo location the Lower Cretaceous is underlain by Middle Cambrian nodular limestone.

Typical Section. Minad LC1A bore (Figs. 15 and 16) is at the northern end of the Tertiary basin which underlies the plains west of Lake Frome. Basic data comprise cutting samples taken at 3-m intervals and self-potential, point resistivity, and gamma-ray logs. The quality of the petrophysical logs is moderate.

Owing to the drilling method, contacts between units were not observed, and detailed subdivision is impossible. Correlation with the Reedy Springs section is obtained through LB19 (Fig. 16).

The basic lithological composition of the Eyre Formation in LC1A and LB19 is very similar to that observed at the Reedy Springs section except for colour differences: subsurface rocks are commonly dark brown to black, resulting from varying content of carbonaceous matter.

Quartz arenite is the dominant rock type particularly in the lower part of the section, with interbeds of carbonaceous siltstone. Some of the sands are also cemented by carbonaceous matter.

The basal unit consists of a conglomeratic sandstone which rests, apparently disconformably, on dark grey siltstone of late Cretaceous age. This contact is readily identified on the petrophysical logs, particularly by the strong negative response on the self-potential log. The Paleocene/Eocene boundary appears recognizable in this bore by lithological and electric log characteristics (Fig. 15).

The top of the Eyre Formation in LC1A is placed at the top of a bed of dense, brown to black, slightly silty carbonaceous claystone, with thin black coaly interbeds having subconchoidal fracture. The coaly beds have a silky lustre on fracture surfaces when dry, and grade down to the more typical rocks of the formation: moderately to well sorted medium-grained carbonaceous polished sand-
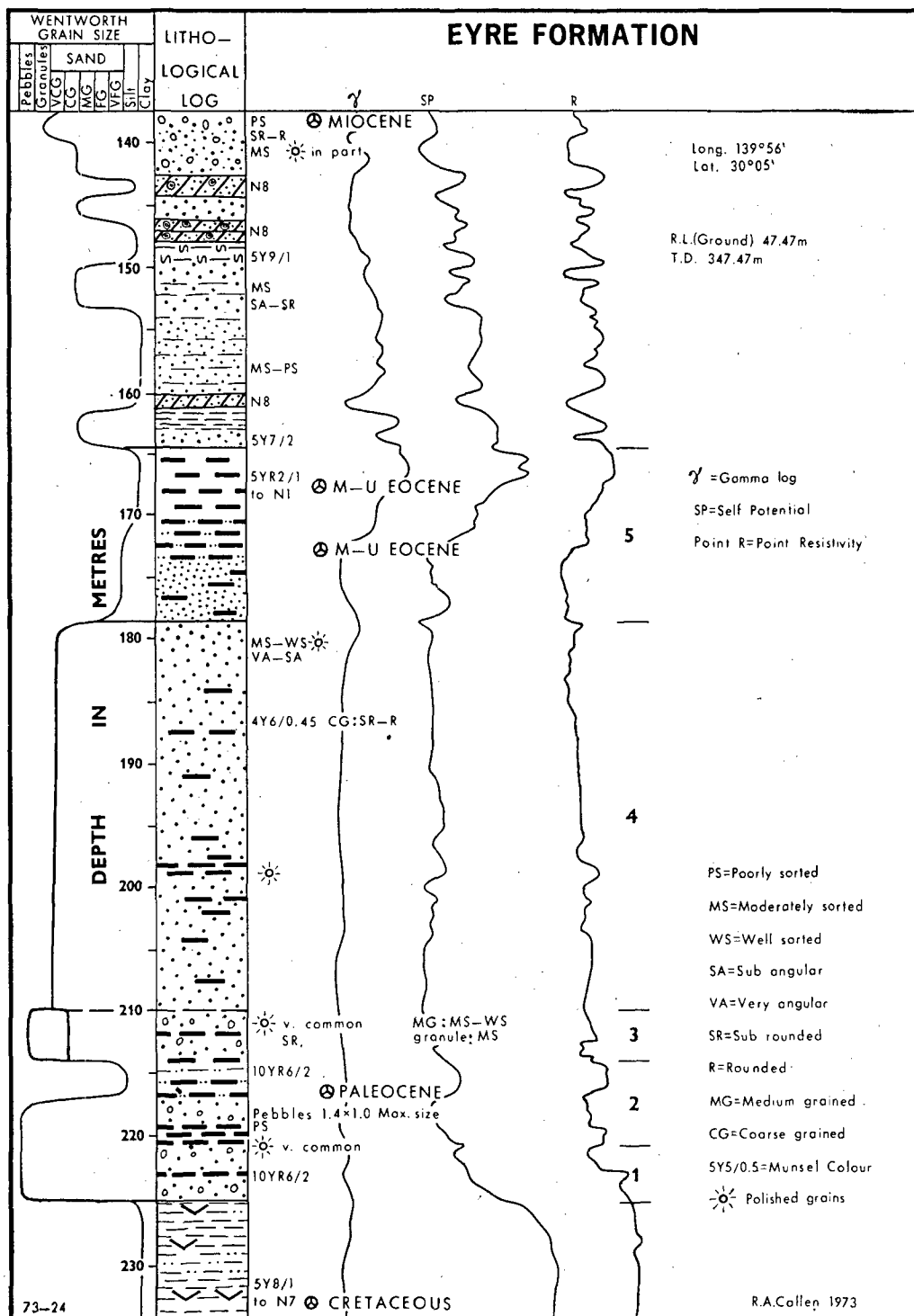
Fig. 15. Composite log of Minad bore LC1A, selected as typical section for the Frome Embayment. The top of the Eyre Formation is placed at 164 m. The contact between Eocene and Paleocene is at the unit 4/5 boundary. The unit-numbers refer to the description in the text. Note the presence of oolitic carbonates near the base of the Miocene. See Fig. 16 for legend.
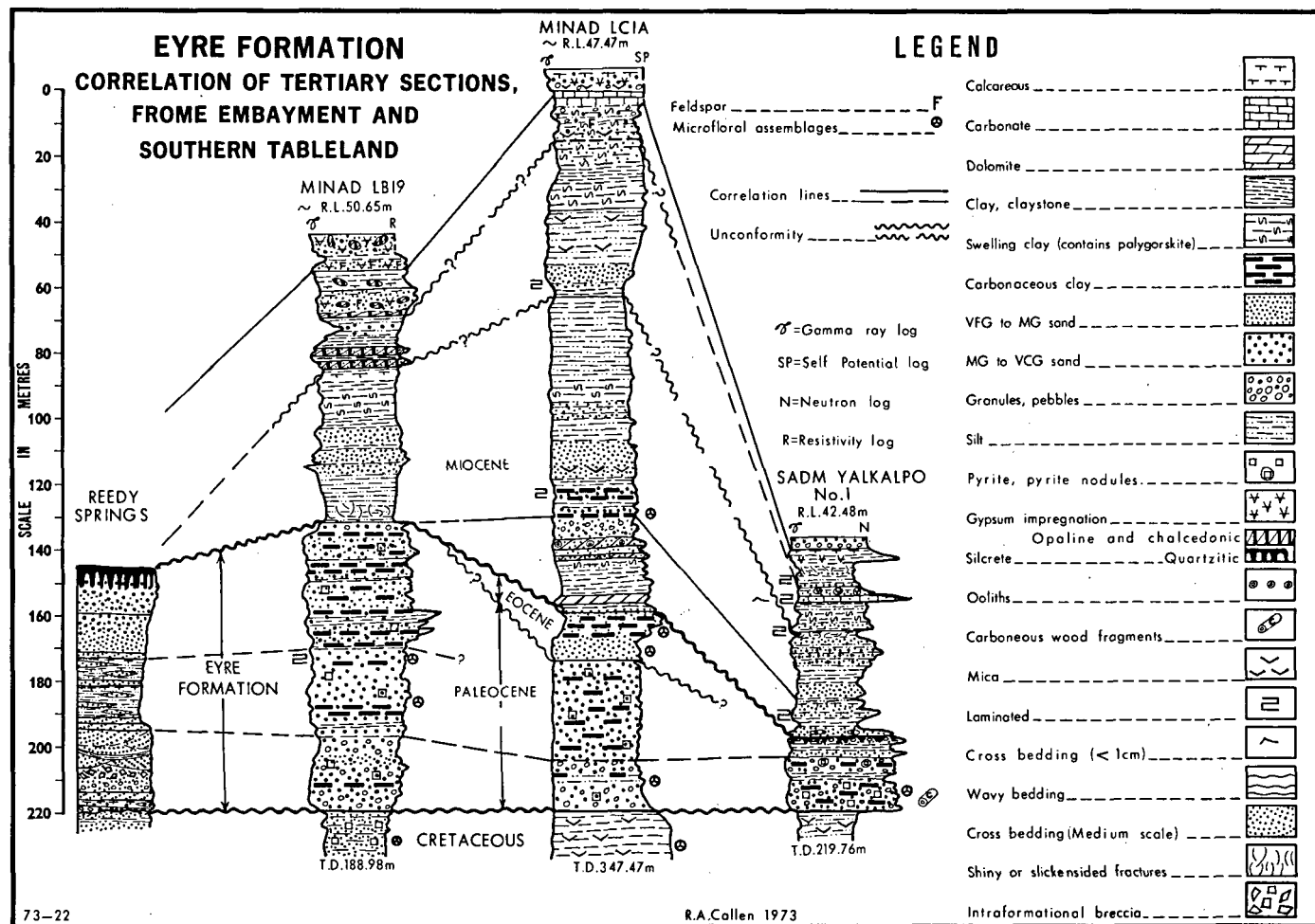
Fig. 16. Correlation chart showing relationship between sections. Other bore hole data, not shown here, were used to assist in the correlation, particularly between Yalkalpo No. 1 and LC1A. Correlation within the Miocene is tentative. New evidence indicates that the top of the Eyre Formation in Yalkalpo No. 1 is at the top of the strong positive departure in the neutron log.

37

stone. Cuttings and electric logs suggest a sharp contact with the Miocene strata at 164 m. The sandstone can be distinguished from that interbedded with the overlying Miocene carbonate rock by its greater range of grainsize, better polish, and carbonaceous content, resulting in darker colours.

The boundary recorded on the petrophysical logs is particularly evident on the point-resistivity and self-potential logs, which show a low-amplitude line with a strong positive departure through the late Eocene carbonaceous silt. On entering the Miocene, a rapidly varying amplitude line begins with a sharp trough at 164 m.

Reference Section Yalkalpo No. 1. Yalkalpo No. 1 stratigraphic well was drilled about midway between Lake Frome and the Barrier Ranges (Fig. 1) on the eastern edge of a buried structural high.

The Eyre Formation in Yalkalpo No. 1 rests on lower Cretaceous Bulldog Shale, the contact presumably being a low-angle regional unconformity (Fig. 16).

The base consists of a dark brown coarse-grained sand loosely cemented by carbonaceous matter, overlain by coarse to medium sand of lighter colour. The sand is commonly bimodal and has polished pebbles and granules of milky quartz and black chert. These beds are the most persistent and widespread in the Eyre Formation. Higher in the sequence coarse sand and silt alternate, contacts being sharp. Scattered polished milky quartz granules or very coarse sand-grains are present, and the top of the silt bed in the uppermost portion of the sequence is weakly silicified. The overlying coarse sand contains rounded 0.5 to 1 cm pebbles of the silicified horizon and polished pebbles.

The contact with the Miocene occurs in a zone of no recovery, but the neutron log indicates a sharp boundary at 55 m. Several features give sharp contrast between the upper part of the Eyre Formation and the Miocene sand; the Miocene sand has more angular grains of higher sphericity than equivalent grains in the underlying beds, is green-grey rather than buff, has thin interbeds of soft bright blue-green clay, and is better sorted.

At 59 m is a second, very sharp, contact. Above it the sand is greenish grey, coarser, and more angular (for equivalent grainsizes) than that below, and contains bright blue-green soft clay bands. This lithology is similar to

that in the Miocene of Wooltana No. 1 between 188 and 195 m. This contact is an alternative choice for the top of the unit, but the first appearance of coarse sand and the response of the neutron log are believed to be more significant.

It should be noted here that in Figure 16 core depths were adjusted and moved up 2 m relative to the neutron and gamma logs, since coincidence between the litholog and several important events could not otherwise be explained, particularly the Tertiary-Cretaceous unconformity. Eocene sediments in nearby Chevron Exploration Pty Ltd bores comprise silty brown to brownish black carbonaceous clay, of which the fine upper sand in Yalkalpo No. 1 may be the leached equivalent.

Recognition of Boundaries. In LB19 the upper boundary of the Eyre Formation is marked by a small sharp positive peak in the resistivity log, with a corresponding low in the self-potential and intermediate values in the gamma log. This peak appears in several other Minad bores, and separates the high resistivity, low self-potential, and low gamma lines typical of the Eyre Formation from the oppositely displaced lines of the overlying strata. Also, the curves for the younger strata have few irregularities, whereas the Eyre Formation shows considerable rapid amplitude variation (note that this is the opposite to LC1A).

The Eyre Formation is overlain unconformably by Miocene beds somewhat similar to the Etadunna Formation (Stirton et al., 1961). The Miocene strata are represented near the base by grey silty clay with carbonaceous lamellae, alternating with fine angular well sorted sand. Still lower in the sequence a series of very fine-grained white, commonly oolitic, dolomite beds are interbedded with the sand and can be correlated with similar beds of Miocene age in Wooltana No. 1. The carbonate beds generally represent the lowest of the Miocene beds in the Lake Frome region and are usually underlain by coarse Eyre Formation sand, e.g. in LC1A. In Wooltana No. 1, drilled in the deeper part of the basin, the carbonate beds are conformably underlain by laminated dark green and black claystone with a diverse Miocene microflora, fish spines, ostracods, and (?) *Potomopyrgus* s.l. (Ludbrook, 1972). The base of this unit was not intersected.

There are two sequences of Miocene carbonate beds of similar appearance, which

could lead to confusion. The lower is inter-bedded with fine-grained well sorted angular sand, but the upper is interbedded with olive grey swelling clay closely resembling the Etadunna Formation. In LC1A both sequences are present, but in LB19 the lower is absent, and in LB17 and LB18 both are missing. In the absence of carbonates, the base of the Miocene sediments can usually be recognized by the last appearance down-hole of hard grey or black clay with shiny fracture surfaces, and the Eyre Formation by the first appear-ance of well sorted polished sand or car-bonaceous silt. The contact is difficult to dis-tinguish where sand is present at the base of the Miocene, as in Yalkalpo No. 1.

The base of the Eyre Formation is always distinct, and is usually represented by an un-conformity: the Tertiary strata rest on fine-grained, well sorted, finely micaceous, dark green-grey shale or sandstone of the late Creta-ceous Winton Formation or older Cretaceous rocks. At the southern edges of the Frome Embayment the underlying rocks may be Middle Cambrian grey limestone or purple shale, or Precambrian metamorphic or igneous rocks of the Olary Block.

Fossil content and age. Except for some ill preserved leaf impressions near Clayton Hill, no macrofossils have been found in the area. Microfloral assemblages ranging in preserva-tion and diversity from fair to excellent have been obtained from a number of subsurface samples, and are discussed under Biostrati-graphy.

Distribution. The Eyre Formation appears to be ubiquitous in the whole of the Frome Embayment and emerges along its eastern margin (Brunker & O'Connell, 1967; Rose et al., 1967).

Available subsurface information indicates that the lower coarse-grained arenite sequence is the most persistent, most widespread unit. It usually consists of upper and lower pebbly beds separated by a thin clayey siltstone bed and is commonly bimodal; it contains large pebbles in places. The unit reaches its maxi-mum known thickness of 90 m near Reedy Springs and thins to 45 m over a broad arch to the west of Lake Frome. Its thickness increases again towards the Barrier Ranges near the New South Wales border. Farther south, near Yarramba, polished grains are absent; the unit is a moderately sorted mica-ceous sandstone, whose coarse fraction is com-posed of angular pitted quartz with rare well rounded quartzite pebbles.

South of Lake Frome the coarse basal unit is absent. Dark brown Paleocene micaceous siltstone, pale bluish green micaceous clay, and silts with root layers rest directly on pre-Tertiary rocks. These are a facies equiva-lent of the basal sandy sediments normally observed within the Embayment.

The higher, Eocene, units of the Eyre Formation, usually finer-grained and carbona-ceous, are widespread but discontinuous. Wopfner suggests that local erosion occurred before the deposition of the Eocene in some areas, as may be seen from Figure 16.

LAKE EYRE REGION (H.W.)

The Lake Eyre Region comprises the Lake Eyre depression (Lake Eyre North and Lake Eyre South) and the monotonous dune fields of the Simpson Desert, bounding the lake to the north, and those of the Tirari Desert adjoining the lake to the east. The Munga-rannie/Mount Gason uplift is taken as the northeastern boundary, and the east-dipping slope of the Western Tablelands (see below) forms a natural demarcation line to the west.

Except for some exposures along the escarp-ments of the Mungarannie/Mount Gason uplift, the Eyre Formation is buried beneath younger sediments and definition relies largely on subsurface data.

S.A. Mines bore Lake Eyre 20 in the south-eastern part of Lake Eyre North (Fig. 1) was chosen as the typical section. It was drilled in 1962 in the search for evaporite minerals (Johns & Ludbrook, 1963) and was con-tinuously cored; the core may be inspected at the core library of the South Australian De-partment of Mines. No petrophysical logs were run.

Typical Section. The Eyre Formation in Lake Eyre Bore 20 consists of mature quartz sand-stone, commonly micaceous and ranging in grainsize from very coarse to very fine. Car-bonaceous laminated silty shale occurs in the lower third of the section and the upper part is characterized by pyritic, micaceous, and clayey sandstone. The sand is generally well sorted, but as in previously described sections grainsize distribution is bimodal in the coarse basal unit. Polished granules and grains are abundant in the basal sand and at irregular intervals throughout the lower two-thirds of the section.
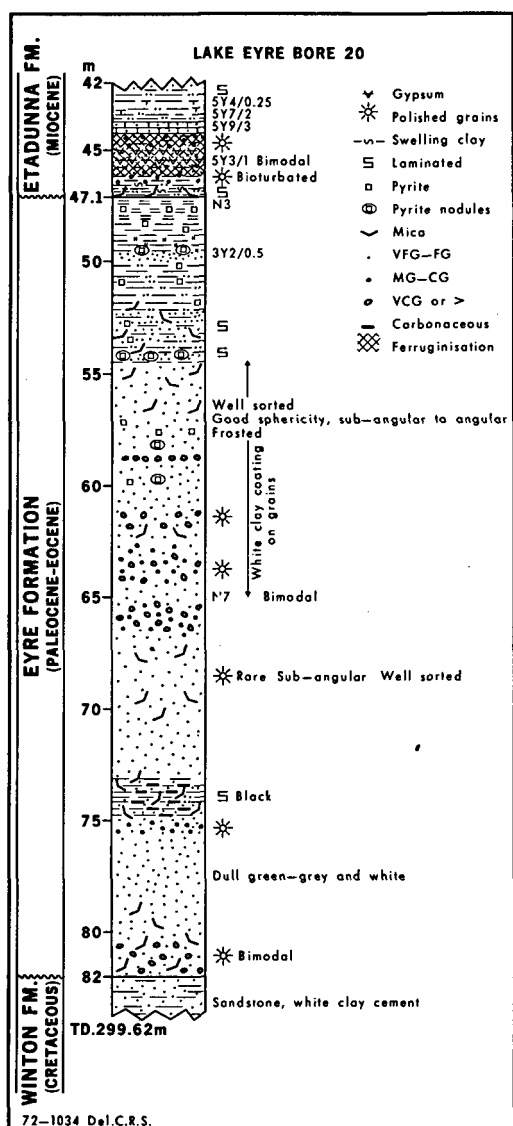
Fig. 17. Typical section of Eyre Formation in Lake Eyre Bore 20. Note that the top is now placed at 47.1 m, excluding the ferruginized sandstones above 47 m.

The rock types are depicted graphically in Figure 17, but no detailed lithological description is given here as they have been described by Johns & Ludbrook (1963). However, we have reinterpreted the upper boundary of the Eyre Formation to exclude the ferruginous pisolite.

The base of the Eyre Formation in Lake Eyre Bore 20 is placed at 82 m below surface. It is marked by a bed of clean coarse sand consisting of rounded, highly polished quartz grains, which contrasts with the clayey and feldspathic sandstone of the underlying Winton Formation.

The upper boundary is determined by the contact with the Etadunna Formation, a sequence composed predominantly of carbonates and first described from an outcrop about 50 km east of Lake Eyre by Stirton *et al.* (1961). At the base of the Etadunna Formation there is commonly a zone of ferruginous pisolite, and such a zone also characterizes the boundary between the Eyre Formation and the Etadunna Formation at 47.1m in Lake Eyre 20 (Fig. 17). Wopfner & Twidale (1967) suggested that the ferruginous pisolite at the base of the Etadunna Formation may be equivalent to the ferruginous pisolite (now termed Doonbara Formation) which unconformably overlies the silcrete of the Cordillo Surface in the Central Fold Belt. It may represent a post-folding period of lateritization.

Fossil content and age. The only fossil occurrences are microfloral assemblages obtained from the Lake Eyre bores (discussed under Biostratigraphy).

Distribution. Owing to the paucity of exposures and drilling data little is known about the distribution of the Eyre Formation in this region. Apart from the typical section and the other bores on Lake Eyre (Johns & Ludbrook, 1963), the formation was identified in the western Simpson Desert (Mokari No. 1 and Purni No. 1), but it appears to be absent in Poonarunna No. 1 immediately northeast of Lake Eyre North, where the Etadunna Formation appears to rest directly on Winton Formation. This may indicate similar structural control of deposition to that described in the Central Fold Belt and the Strzelecki Desert.

Coarse sand with lenses of polished pebble conglomerate is exposed on low mesas southwest of Lake Eyre South and may represent reduced or stripped sections of Eyre Formation.

Extensive exposures occur on the large surface structures along the Birdsville track, such as the Mount Gason/Mungarannie Structure.

WESTERN TABLELANDS (H.W.)

The Western Tablelands comprise the stony tablelands west and northwest of Lake Eyre North and west of the Simpson Desert. The western limit is loosely defined by the western margin of the Great Artesian Basin. Within the eastern part a number of well defined sur-

face structures such as the Oodnadatta, Mount Sarah, Mount Alexander, and Dalhousie Anticlines are recognizable. Farther west, fold-structures become more subdued, leading to the development of extensive, gently warped plateaux.

Some steeper-dipping strata, with dips up to 45°, resulted from fault-deformation along the eastern margin of the Peake and Denison Ranges and at Mount Harvey, south of Oodnadatta (Freytag et al., 1967). In the Oodnadatta 1:250 000 Sheet area (Freytag et al., 1967) sediments now recognized as equivalents of the Eyre Formation were mapped as 'Macumba Sandstone'. Although this name was published on the geological map and used in other publications (Freytag, 1966; Wopfner et al., 1970), it was never defined formally, and it is now recognized as a synonym of Eyre Formation.

Typical Section. The type section originally intended for the 'Macumba Sandstone' becomes the typical section of the Eyre Formation in the Western Tablelands. It is located at a sheer cliff-face southeast below the trig point of Mount Alexander, some 57 km northeast of Oodnadatta (Fig. 1).

At this section and over the whole of the Oodnadatta 1:250 000 Sheet area, the Eyre Formation rests upon upper sediments of the Oodnadatta Formation. Although an unconformable relation between the two formations is not evident in any one outcrop it is well demonstrated on a regional scale; to the southwest the Eyre Formation rests on progressively older sediments, being in contact with the Lower Cretaceous Bulldog Shale southwest of the Arckaringa Creek, whereas to the north in the Dalhousie Anticline, Upper Cretaceous Winton Formation forms the base.

The Eyre Formation consists primarily of quartz arenite with very few or no shale interbeds. Although not particularly well developed in the typical section, a thin pebble sandstone or conglomerate commonly occurs at or near the base of the formation (Fig. 18); it is again distinctly bimodal. The pebbles and granules are well rounded, and many are highly polished. The components represent a mature assemblage consisting of white or translucent quartz, grey and black chert, quartzite, and agate.

The higher units consist of fine to coarse quartz sandstone, usually kaolinitic and friable,
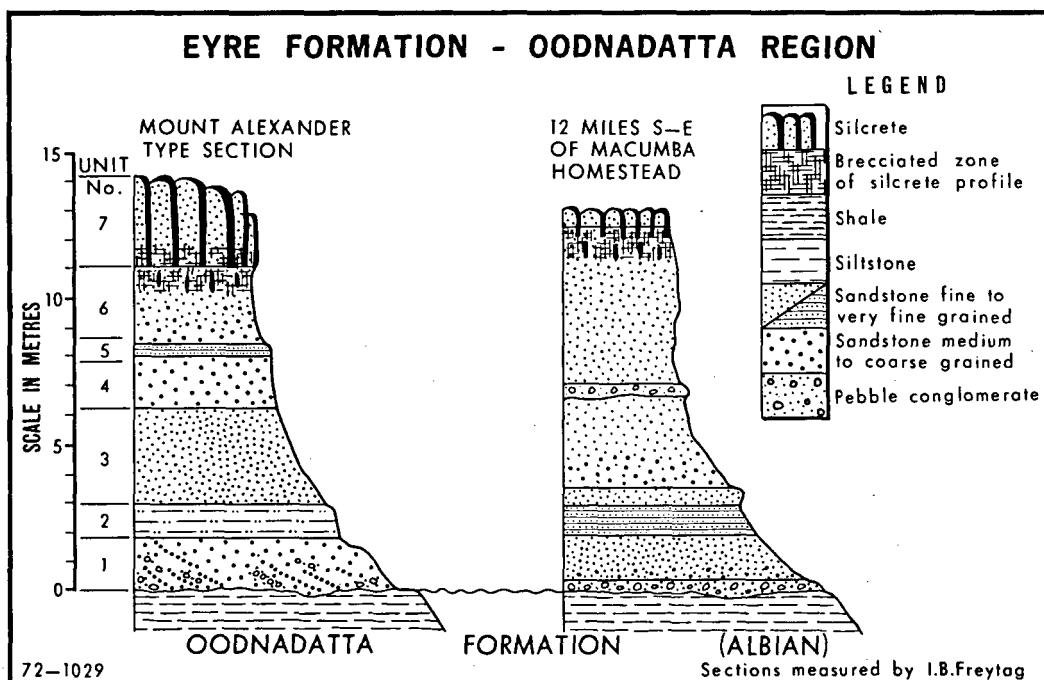

Fig. 18. Sections of Eyre Formation in the Western Tableland region.

with some white siltstone interbeds. The light colours are due to the deep weathering effect of the silcrete profile.

The top of the formation is defined by a generally columnar sandy silcrete identical in appearance and composition with the silcrete of the Cordillo Surface. Stratigraphically higher parts of the Eyre Formation may show incipient silicification, and some reworked silcrete pebbles may also be present near the top.

The typical section and a reference section are depicted in Figure 18.

Fossil Content and Age. No fossils are known from the immediate area. Some leaf-impressions occur in the northern part of the Stuart Ranges. No palynological dates are available.

Distribution. The total thickness of the Eyre Formation in the typical section is only about 14 m, which is an average overall thickness in the outcrop area. The formation thickens eastward as it descends towards the Lake Eyre Depression.

In outcrop the formation is generally found at the top of mesas, tablelands, and dissected plateaux; these occurrences are interpreted as the remnants of a once ubiquitous sandstone blanket.

Along the eastern margin of the area, the Eyre Formation dips gently beneath the Simpson Desert and Lake Eyre, where it joins up with its counterpart in that region.

SOUTHWESTERN TABLELANDS (H.W.)

The Southern Tablelands comprise the area south and southwest of Lake Eyre and extend onto the Precambrian terrain north and west of Lake Torrens. The dominant feature is an arcuate zone of dissected tableland extending from the Coober Pedy opal fields in the Stuart Ranges to just south of Lake Eyre South.

The Eyre Formation caps the mesas and tablelands, with its top usually silicified and transformed into silcrete.

No section has been measured, and the designation of a typical section has to await further work. Excellent exposures have been observed by Wopfner in the headwaters of Stuarts Creek some 60 km southwest of Lake Eyre South in the southwestern Curdimurka 1:250 000 Sheet area.

As in the other areas described, the Eyre Formation consists substantially of mature quartz sandstone with bands and lenses of granule to pebble conglomerate at the base.

Their components are generally well rounded and highly polished. Upwards-fining sequences are not uncommon. Interspersed with the arenite are beds and lenses of clean, commonly laminated shale.

This shale was apparently an ideal medium for the preservation of plant fossils; this area contains by far the greatest number of plant-fossil localities. The fossils, mainly leaves and branchlets, occur as impressions usually in silicified portions of the shale. Specific localities are known from south of Lake Eyre (Forbes, 1966), and from the country between the Mount Eba and Twin homesteads, about 150 km west-southwest of Lake Eyre, where several localities are known and some aspects of the floras have been described by Offler (1969).

Palynological dates have been obtained from two samples from seismic shot-holes YB 30 and LPC 60 (Fig. 1).

The thickness of the Eyre Formation in this region rarely exceeds 30 m and is generally less. The present distribution is directly related to the remnants of the tableland described above.

Between this arc and the area of the Western Tableland there is a region, west and southwest of the Peake and Denison Ranges and roughly centred, on Lake Cadibarrawirracanna, where the Eyre Formation is completely absent. It is thought that uplift and doming of this region in middle and late Tertiary time (Wopfner, 1968) caused erosional stripping of a thick sediment layer, including the Eyre Formation.

BIOSTRATIGRAPHY (W.K.H.)

Apart from arthropod (acarine) setae and tarsal claws, in palynological preparations, similar to those described by Southcott & Lange (1971), the only fossils recorded are those of plants: spores, pollen and dinoflagellate cysts (Harris, 1973) from subsurface sections, and leaf, and stem, fruit moulds in some surface exposures (Tate, 1882; Chapman, 1937; Offler, 1969). The macrofossils have little biostratigraphic value and will not be discussed further.

Previous palynological studies are those of Balme (*in* Johns & Ludbrook, 1963) on Lake Eyre Bore 20, and the taxonomic works of Cookson (1950, 1953, 1956, 1957) and Cookson & Pike (1953 a & b, 1954, a & b) on core samples from Lake Cootabarlow bore. Holotypes of two species, *Microfoveolatosporites fromensis* (Cookson) and *Ephedripites*

notensis (Cookson), and a paratype of *Tricol-pites gillii* (Cookson), are from a core sample at 170 m in this bore; 13 other species are recorded of which four have figured specimens from various levels in Cootabarlow.

Data on palynological samples are available on open file at the Geological Survey of South Australia (*Geol. Surv. S. Aust. Rep. Book* 73/89).

Biostratigraphic framework. The biostratigraphy and palynology of South Australian early Tertiary sediments have been discussed by Harris (1971) and McGowran *et al.* (1971). More recently Stover & Evans (1973) and Stover & Partridge (1973) proposed a scheme similar to that of Harris (1971) for the Gippsland Basin. The biostratigraphy of the Eyre Formation can be discussed in relation to these papers. The correlation of the Eyre Formation with units in the Murray Basin and the Gambier Embayment of the Otway Basin is discussed under Regional Correlation.

Palynological studies have been hampered by several factors. Except for Lake Eyre Bore 20 and Cootabarlow No. 2, few bores have passed through and sampled adequately the complete succession. Another factor is the preponderance of sand within the sequence — mostly unfavourable for recovering palynomorphs. It is commonly leached by groundwater movements laterally and vertically. Thirdly, most samples are derived from cuttings and some caution is needed in interpreting the results. However, most show little or no contamination and those that are obviously contaminated have been omitted. Additionally, there are no sections in which all zones have been identified.

Succession of biostratigraphic units
Gambierina edwardsii Zone. The oldest, most widespread unit is that of the *Gambierina edwardsii* Zone. It is characterized by a low diversity and low frequency of *Nothofagidites* spp., abundant *Australopollis obscurus* (Harris), *Proteacidites incurvatus* Cookson, *P. grandis* Cookson, *P. fromensis* Harris, *P. angulatus* Stover, *Latrobosporites ohaiensis* (Couper), *L. crassus* (Harris), *Lygistepollenites balmei* (Cookson), *Tetracolporites verrucosus* Stover, and *Camarozonosporites bullatus* (Harris).

Rare occurrences include *Amosopollis dilwynensis* Harris, *Dryptopollenites semilunatus* Stover, *Anacolosidites acutullus* Cookson &

Pike, *Cupanieidites orthoteicus* Cookson & Pike, *Proteacidites kopiensis* Harris, *Microfoveolatosporites fromensis* (Cookson), *Tricolpites phillipsii* Stover, and *Intratriporopollenites notabilis* (Harris). This Zone invariably carries an assemblage (three species) of non-marine dino-flagellate cysts that have been described by Harris (1973).

Despite the absence of *G. edwardsii*, the unit described here is correlated with the *G. edwardsii* Zone in the Otway and Murray Basins. In particular the abundance of *A. obscurus* and the presence of *L. balmei, L. ohaiensis*, and *P. fromensis* support this correlation. There is some evidence from the presence of the rare species *A. acutullus, D. semilunatus, I. notabilis*, and *P. kopiensis* that the unit lies near the *G. edwardsii/Cupanieidites orthoteichus* boundary. It is correlated in part with the *Lygistepollenites balmei* zone of Stover & Evans (1973) and is of late Paleocene age.

The unit extends from Lake Eyre Bore 20 in the west to Moomba No. 4 and Patchawarra in the north and is widespread in the Frome Embayment to the south. Near the margin of the Frome Embayment it is often missing (e.g. B240C3 & QDH.16), reflecting erosion and tectonic instability before younger units were laid down.

Proteacidites confragosus Zone. In the Frome Embayment, this zone is known from QDH15, Pacminex 7A, and Sedimentary Uranium B240C3 (Fig. 1). It has not been recognized outside this area, perhaps owing to inadequate sampling. The zone is characterized by *P. confragosus* Harris and *P. asperopolus* Stover & Evans, with generally a low frequency of *Nothofagidites* spp. and high *Haloragacidites harrisii* (Couper) and *Casuarinidites cainozoicus* (Cookson & Pike). *Sapotaceoidaepollenites rotundus* Harris is also abundant. The zone is middle Eocene (McGowran *et al.*, 1971) and is a correlative of the *Proteacidites asperopolus* Zone of Stover & Evans (1973).

Proteacidites pachypolus Zone. All samples except one (Chevron QDH18, S2459) from the *P. pachypolus* zone appear to be low in the zone. The assemblages are generally diverse and are dominated by *Nothofagidites* spp., except in Lake Eyre Bore 20 (at 58.2 m) and Lake Cootabarlow No. 2 (at 157.0 m), where the assemblage is dominated by *C. cainozoicus;* the microflora is not diverse and does not include *P. confragosus* or *P. aspero-*
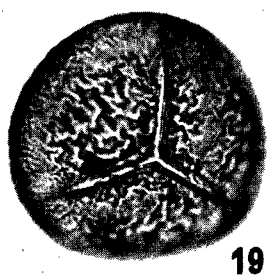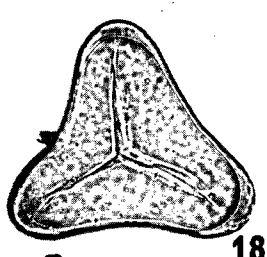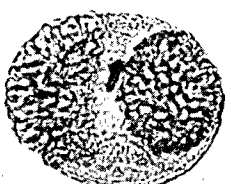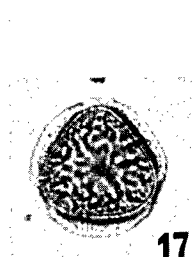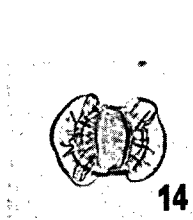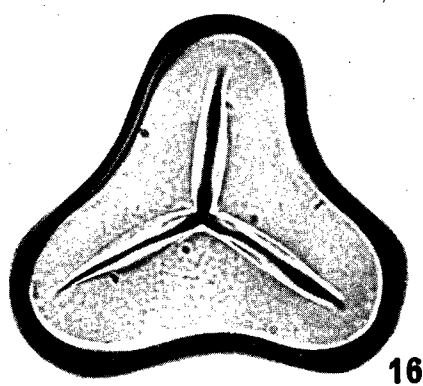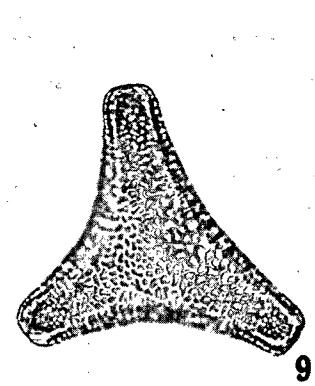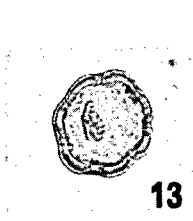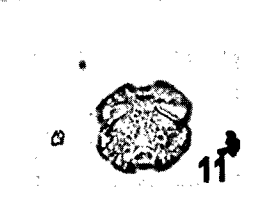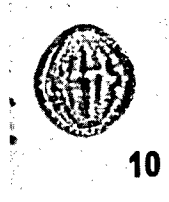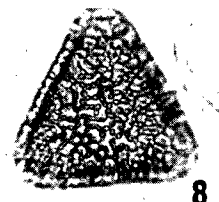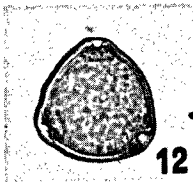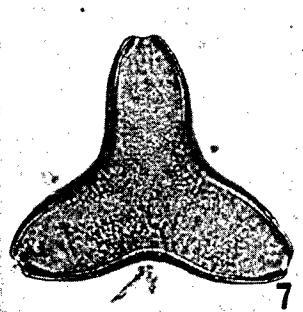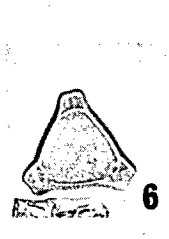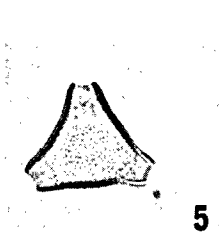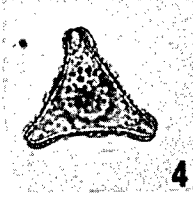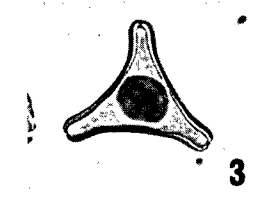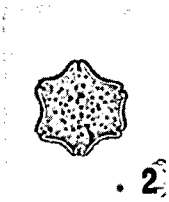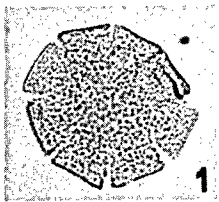
polus and therefore does not belong to the *P. confragosus* Zone. Furthermore, this assemblage succeeds (assuming that there has been no transposition of core) one containing dominant abundant *Nothofagidites* spp.

Other more typical assemblages of the *P. pachypolus* Zone contain, together with the nominate species, *P. incurvatus, P. reticulatus,* rare *P. rectomarginis* Cookson, rare *N. asperus* (Cookson), *Heliciporites astrus* Stover, and *Schizocolpus marlinensis* Stover. The rarity of *N. asperus* and *P. rectomarginis* indicates a position low in the *P. pachypolus* Zone. Similar microfloras are present in the Eucla Basin, where they accompany middle Eocene foraminiferal assemblages (Lindsay & Harris, 1973). The zone extends from seismic shotholes YB30 and LPC60 in the west to Lake Eyre Bore 20 and into the Frome Embayment. It has not been identified in the northern region, but this may be due to inadequate sampling.

One sample representative of late phase of the *P. pachypolus* Zone was identified in Chevron QDH18. In this assemblage *Nothofagidites* spp. are co-dominant with bisaccate gymnosperm pollen. Very few species are present. On this limited evidence a tentative upper Eocene age is assigned to the microflora.

Summary of Age

The most widespread biostratigraphic unit, and the earliest Tertiary assemblage, is that of the *G. edwardsii* Zone or its correlative and is middle to late Paleocene. The later phase begins in the middle Eocene (*P. confragosus*

Zone) and may extend into the late Eocene. This interpretation necessitates a break corresponding to the early Eocene within the formation. Although only three bores, Lake Eyre Bore 20, Cootabarlow Bore 2, and LCIA, have both Paleocene and Eocene zones in succession, there is evidence to suggest that the break is real. No microfloras equivalent to the *Cupanieidites orthoteichus* Zone of Harris (1971) or its correlative in the Gippsland Basin, the *Malvacipollis diversus* Zone of Stover & Evans (1973), have yet been identified, and only close sampling at about this level in future bores will substantiate this hypothesis.

DEPOSITIONAL ENVIRONMENT

The available data allow us to conclude with a high degree of confidence that the Eyre Formation formed as an almost continuous, although thin, sediment blanket over the whole of the central and western Great Artesian Basin. In subsurface the continuity of the Eyre Formation is still preserved, whereas in the regions of the surface anticlines the formation was dissected by erosion and partly removed.

The dominant fossils were terrestrial spores and pollen and planktonic nonmarine dinoflagellate cysts (Harris, 1973). This fossil content together with the lithological composition clearly shows that the Eyre Formation was laid down in fresh water; there is no evidence of marine influence within the basin. Thus a depositional model is required which will

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PLATE 1. Characteristic microfossils from the Eyre Formation. All figures *c.* x 560 in normal transmitted light. The slide and sample number is followed by the coordinates of the specimen measured on the Leitz Orthoplan microscope in the Geological Survey.

Fig. 1. *Nothofagidites asperus* (Cookson). S2459/1; 31.9: 112.0.
Fig. 2. *N. falcatus* (Cookson). S2459/1; 26.5: 106.9.
Fig. 3. *Proteacidites pachypolus* Cookson & Pike. S546/1; 51.6: 103.3.
Fig. 4. *P. asperopolus* Stover & Evans. S2486/1; 31.4: 107.6.
Fig. 5. *P. angulatus* Stover. S2566/1; 29.6: 93.9.
Fig. 6. *P.* aff. *P. angulatus* Stover. S2566/1; 27.7: 107.5. Notice the separation of the exine layers near the apertures.
Fig. 7. *P. fromensis* Harris. S2573/1; 39.5: 108.9.
Fig. 8. *P. confragosus* Harris. S2458/1; 25.5: 105.0.
Fig. 9. *P.* cf. *P. grandis* Cookson. S2573/1; 23.3: 103.6.
Fig. 10 & 11. *Tetracolporites verrucosus* Stover. Fig. 10, S2566/1; 33.8: 108.6. Fig. 11. S2566/1; 31.9: 108.4.
Fig. 12. *Haloragacidites harrisii* (Couper). S2458/1; 31.0: 100.3.
Fig. 13. *Australopollis obscurus* Harris. S2573/1; 40.0: 109.4.
Fig. 14. *Podocarpidites* cf. *P. exiguus* Harris. S2573/1; 43.3: 101.5.
Fig. 15. *Lygistepollenites* cf. *L. balmei* (Cookson). S2566/1; 39.6: 106.7. This specimen does not have the well developed sacci typical of the species.
Fig. 16. *Cyathidites splendens* Harris. S2566/1; 37.9: 103.2.
Fig. 17. *Krauselisporites papillatus* Harris. S2596/1; 26.4: 111.6.
Fig. 18. *"Triletes" gigantis* Cookson. S2596/1; 29.1: 107.2.
Fig. 19. *Latrobosporites crassus* Harris. S2573/2; 37.7: 106.9.

explain the distribution of a blanket consisting of clastic sediments, many of them coarse-grained, and lignite over an area in excess of 350 000 km^2.

The onset of deposition of the Eyre Formation is characterized by an almost ubiquitous basal layer of coarse clastics consisting of pebble or granule conglomerate usually composed of highly polished, resistant material. Although the contact with the underlying strata commonly exhibits small scour and other erosional structures, overall it is quite planar. Sharply incised large channels are absent, and if major channels are developed they have low-angle profiles and apparently are restricted to regions close to source areas.

These features suggest a sudden onset of this depositional event and ready availability of abundant clastic material within the source area. A planar surface of deposition would have been provided by the plain which had developed as the result of depositional regression during Cenomanian and Turonian time.

Epeirogenic movements in the Paleocene are thought to have been responsible for the sudden onset of the deposition of the Eyre Formation. Uplift of the source area, in particular the Olary Block and the Barrier Ranges/Cobar region, would have created the gradients necessary for the establishment of major drainage systems. Initially the drainage would have consisted of braided streams of just sufficient gradient to allow the transport and spreading of large volumes of coarse material — particularly during periods of flooding — but of insufficient gradient to facilitate major erosional incision under the given sediment load (Tricart, 1961).

The rudaceous and coarse arenaceous material was transported essentially by bed-load movement. However, the rivers must have also carried large concentrations of suspended matter in order to produce the highly polished grains typical of the Eyre Formation.

Marginal peat swamps, inundated and covered with sand during floods and subsequent diagenetic migration, may account for the coarse very carbonaceous sand observed for instance at the base of the Eyre Formation in Yalkalpo No. 1.

The abundant pebbles of silicified wood and agate in the basal units of the Eyre Formation clearly identify the source. They could only have been derived from the Jurassic sandstone along the southern margin of the Great Artes-

ian Basin. There is little doubt (Evans & Hawkins, 1967; Thornton, 1972) that during Jurassic and Cretaceous time the Murray Basin was part of the Great Artesian Basin. The structural high from the Olary Block to the Cobar Hill, which now separates the two basins, was uplifted in early Tertiary time. Mesozoic sediments which covered it, together with other erosional debris, were shed both northward (Fig. 10) and southward.

Increased angularity and mica content in the southeastern Frome Embayment also suggest a source in the Olary Region and the Barrier Ranges. Some mica may have been supplied from reworked Cadna-owie Formation.

The gradational upwards fining of the sediments, for example from Unit 2 to Unit 7 in the Innamincka type section, and also in other areas, must reflect a decrease in transport energy caused by a decrease in gradient; the source areas were lowered by erosion and the depositional area filled up. This is similar to the model of repeatedly retreating scarp erosion described by Selley (1970, p. 44) but at much smaller vertical scale.

With the decrease in gradient the character of the rivers changed from the initial braided pattern to flood plains with incised meanders. Sequences suggestive of point bars may be observed in the Innamincka type section (e.g. Unit 8 in Fig. 2) and in the Innamincka Dome. Clear evidence for channel development can also be observed in the Innamincka type section, near Callamurra waterhole, and on the northeastern side of the Tickerna Structure south of Cooper Creek (Fig. 19).

The micaceous siltstone commonly associated with the carbonaceous deposits is also typical of a flood-plain environment, and the lignite would have developed in back-swamps.

Changes in grainsize within the section may be explained, at least in part, by meander migration. One would expect minor tectonic adjustments to have been involved also in a sequence where the thickness distribution is so closely related to major structural trends (Figs. 8 & 10).

In the middle Eocene an apparent renewal of epeirogenetic movements increased the erosional gradient, leading to considerable initial erosion soon followed by aggradation and deposition as the gradient decreased.

In the western area the source appears to have been in the north and northwest, but
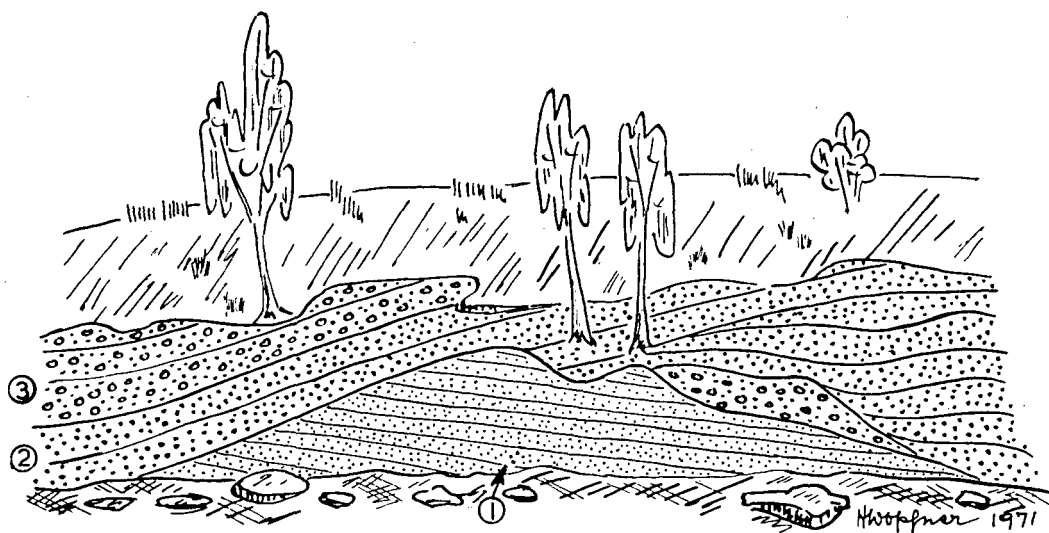
Fig. 19. Sketch of exposure of Eyre Formation at Tickerna, southeast of Innamincka. The outcrop exhibits marked intraformational erosion, presumably caused by channel migration. Width of sketch about 12 m. (1) Fine-grained, thinly bedded sandstone; (2) Medium to coarse-grained, semi-friable sandstone; (3) Very coarse sandstone and pebble conglomerate.

insufficient evidence is at hand for any meaningful reconstruction.

The Southwestern Tablelands seem to have been an area of lacustrine deposition, the fine quiet-water clay and silt providing an excellent medium for the preservation of leaves and other plant macrofossils.

The depositional model developed for the Eyre Formation requires large extensive river systems, and one must therefore also accept that this environment was exoreic. However, at the present state of our knowledge one can only speculate where such an 'overflow' existed. Thickness distribution and grainsize distribution do not support such an overflow across the Olary Block. Exit to the sea may have been via Lake Torrens, but no Paleocene sediments are known from this region. Paleocene sediments are known south of Eyre Peninsula, and an interconnexion between them and the Eyre Formation would appear the most elegant solution. A further alternative connexion may be from the area of the Southwestern Tablelands to the Eucla Basin, but here middle Eocene sediments rest directly on basement or lower Cretaceous sedimentary rocks (Lindsay & Harris, 1973).

CLIMATE AND THE AGE OF SILCRETE

Climatic conditions during the deposition of the Eyre Formation can only be assessed in a general way. Current structures and the presence of lignite beds suggest a fairly high rate of precipitation, possibly with large seasonal volumes accounting for high transport energy.

Microfloral evidence suggests high rainfall and moderately high temperature during the Paleocene. Species that may be considered to have tropical or sub-tropical affinities are *Anacolosidites acutullus* and *Cupanieidites orthoteichus*. The Eocene saw a general warming with increased precipitation. The dominance of *Nothofagidites* spp. (pollen of a rain-forest genus), particularly the *brassi* group in the assemblages, attests to this.

Towards the end of the depositional phase in Eocene time increased seasonal aridity is indicated by the incipient quartzitic layers (silcrete) within the upper part of the sequence, both in outcrop and in subsurface. Since the subsurface silcrete is overlain by fossiliferous Miocene beds a reasonably accurate time limit for the formation of the quartzitic, generally columnar, silcrete can be given. Its formation extended over the late Eocene and the Oligocene; as it was dissected before the Miocene beds were deposited, its formation presumably ended in about late Oligocene time. This contrasts with the conclusion by Stephens (1971, p. 42) 'that the major periods of formation were in Pliocene time'.

It throws doubt also on the contemporaneity of the formation of silcrete and laterites and favours their separate development, as suggested by Wopfner (1960) and Wopfner & Twidale (1967).

REGIONAL CORRELATION
Murray Basin

Mature quartz sandstone, composed of well rounded and generally well sorted coarse to fine quartz, forms the base of the sediment fill of the Tertiary Murray Basin, situated south of the Olary/Broken Hill Block. Stratigraphically higher, the sandstone becomes finer and interbedded with siltstone, carbonaceous-micaceous shale, and lignite, and marine phases of the Buccleuch Beds (Lindsay & Bonnett, 1973).

The basal sequence is referred to as the Renmark Beds (Harris, 1966), and not only has lithologically identical features with the Eyre Formation but also is of similar age, ranging from Paleocene to upper Eocene (Harris, op. cit.). Thus the Renmark Beds are in part a time-rock equivalent of the Eyre Formation, although they are a more complete sequence.

Whereas the Murray Basin and the Great Artesian Basin interconnected during Mesozoic time the sedimentary basins in which the Eyre Formation and the Renmark Beds were deposited were separated by the Olary/Broken Hill Block and the Cobar High, which formed during the early Tertiary and were the main source area supplying erosional detritus into both basins. Much of this detritus was derived from Upper Jurassic and Lower Cretaceous sediments.

Otway Basin/Gambier Embayment

Early Tertiary sediments are invariably marine or marginal marine, and their biostratigraphy has been discussed by McGowran et al. (1971) and Harris (1971). The Paleocene G. edwardsii Zone of the Eyre Formation correlates with the Dilwyn Formation in part (at about 'Rivernook' level, Harris, 1965), the P. confragosus Zone with the Burrungule Member of the Knight Formation, and the P. pachypolus Zone with the Kongorong Sand and the lower part of the Lacepede Formation.

Eucla Basin

Recent studies (Lindsay & Harris, 1973) on the Pidinga Formation indicate an age low in the P. pachypolus Zone, and the microfloras are associated with marine middle Eocene

foraminifera and dinoflagellate cysts. No older Tertiary sediments are known.

Pirie-Torrens Basin

The Tertiary sequence encountered during drilling near Wilkatana by SANTOS Ltd is very similar, even lithologically identical, to the basal Eyre Formation. Bimodal basal coarse sandstone, often impregnated with carbonaceous matter, is very common, as are interbeds of lignite and carbonaceous shale. Palynological studies (Harris, in Johns, 1968; Harris, 1972) from these and other wells indicate that Tertiary sedimentation did not begin until the P. confragosus Zone and continued into the P. pachypolus Zone. As Paleocene sediments are known offshore from Eyre Peninsula (Duntroon Basin), the presence in the Pirie-Torrens Basin of time-rock equivalents of the Eyre Formation cannot as yet be excluded.

St Vincent Basin

The oldest Tertiary sediments known in the St Vincent Basin are middle Eocene Proteacidites confragosus Zone (McGowran et al., 1970) followed by middle and upper Eocene sediments. These could be regarded as time equivalents, in part, of the younger phase of the Eyre Formation.

Southwestern Queensland

Whitehouse (1954, p. 12) related sandstone, mudstone, and conglomerate of the channel country directly to the 'Eyrian Formation' in South Australia. He specifically separated them from 'the loosely compacted sediments, apparently of Pliocene age, of the Glendower Formation'. He also emphasized the fact that the Glendower Formation contains 'boulders of billy' i.e. quartzitic silcrete, clearly indicating that it postdates the formation of the quartzitic silcrete.

Workers of the Bureau of Mineral Resources mapping in southwest Queensland have included such a variety of rock units within the name Glendower Formation that the meaning of the term has become indistinct and vague. For instance, Senior et al. (1968, p. 23 and p. 26) stated: 'Identical sediments to those of the Glendower Formation occur in the eastern Cordillo Sheet area to the west of the Barrolka Sheet area. These have been described by Wopfner (1963), who proposed the name Mount Howie Sandstone', and ' . . . the Mount Howie Sandstone is directly correlative with the Glendower Formation'.

Petroleum companies operating in the Cooper Basin have confused matters further by applying the term Glendower Formation almost as a synonym for the interval of surface casing. The well completion report for Alliance Packsaddle No. 1 on the western nose of the Innamincka Dome (Fig. 8) (Mulready, 1970) recorded 'Glendower Formation from surface to 510 ft' when the contact between the Cretaceous (Winton Formation) and the Tertiary (Eyre Formation) can be seen on the access road and at the foot of the escarpment less than 30 m below the well location.

Let us summarize the facts:

(1) The Mount Howie Sandstone is a feldspathic, kaolinitic sandstone restricted to ancient river channels deeply incised into the Winton Formation. Its macroflora, although not conclusively diagnostic, is different from that in the Eyre Formation.

(2) The Eyre Formation consists of mature clastics, primarily quartz arenite, and forms a widespread continuous sediment blanket which in places rests disconformably on typical Mount Howie Sandstone (columns 3 and 4 in Fig. 8). Its lower part is Paleocene.

(3) The Glendower Formation as defined by Whitehouse consists of ferruginous sands with reworked quartzitic silcrete. Its equivalents rest disconformably or unconformably on Eyre Formation.

Using the principle of superposition we conclude that:

(a) the Mount Howie Sandstone represents the final episode of the Cretaceous regression;

(b) the Eyre Formation is a new event completely independent from controls governing the Cretaceous deposition;

(c) the Glendower Formation (sensu stricto) postdates the deformation of the Eyre Formation; and

(d) on present evidence it would appear that the Tertiary depositional phase within the Great Artesian Basin ended with the deposition of the Etadunna Formation and its equivalents in Miocene time.

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REFERENCES

BRUNKER, R., & O'CONNELL, P., 1967: Geological atlas of Australia, 1:250 000 series. Cobham Lake Sheet, SH/54-11. Geol. Surv. N.S.W.

CHAPMAN, F., 1937: Descriptions of Tertiary plant remains from central Australia and from other Australian localities. Trans. Roy. Soc. S. Aust., 61, pp. 1-16.

COATS, R. P., & BLISSETT, A. H., 1971: Regional and economic geology of the Mount Painter Province. Geol. Surv. S. Aust. Bull. 43.

COOKSON, I. C., 1950: Fossil pollen grains of proteaceous type from Tertiary deposits in Australia. Aust J. Sci. Res. B., 3, pp. 166-176.

COOKSON, I. C., 1953: The identification of the sporomorph Phylocladidites and Dacrydium and its distribution in southern Tertiary deposits. Aust. J. Bot., 1, pp. 64-70.

COOKSON, I. C. 1956: Pollen grains of the Ephedra type in Australian Tertiary deposits. Nature, 177, pp. 47-48.

COOKSON, I. C., 1957: On some Australian Tertiary spores and pollen grains that extend the geological and geographical distribution of living genera. Proc. Roy. Soc. Vic., 69, pp. 41-53.

COOKSON, I. C., & PIKE, K. M., 1953a: The Tertiary occurrence of *Podocarpus* (section *Dacrycarpus*) in Australia and Tasmania. *Aust. J. Bot.,* 1, pp. 71-82.

COOKSON, I. C., & PIKE, K. M., 1953b: A contribution to the Tertiary occurrence of *Dacrydium* in the Australian region. *Aust. J. Bot.,* 1, pp. 474-484.

COOKSON, I. C., & PIKE, K. M., 1954a: The fossil occurrence of *Phyllocladus* and two other Podocarpaceous types in Australia. *Aust. J. Bot.,* 2, pp. 60-68.

COOKSON, I. C., & PIKE, K. M., 1954b: Some dicotyledonous pollen types from Cainozoic deposits in the Australian region. *Aust. J. Bot.,* 2, pp. 197-219.

DAVID, T. W. E., 1932: Explanatory notes to accompany a new geological map of the Commonwealth of Australia. *Counc. sci. ind. Res. Aust.,* 1-177.

DAVID, T. W. E., & BROWNE, W. R., 1950: *The Geology of the Commonwealth of Australia, Vol.* 1. Arnold, London.

EVANS, P. R., & HAWKINS, P. J. 1967: The Cretaceous below the Murray Basin. *Bur. Miner. Resour. Aust. Rec.* 1967/37 (unpubl.).

FOLK, R. L., ANDREWS, P. B., & LEWIS, D. W., 1970: Detrital sedimentary rock classification and nomenclature for use in New Zealand. *N.Z. J. Geol. Geophys.,* 13, pp. 937-968.

FORBES, B. G., 1966: The geology of the Marree 1:250 000 map area. *Geol. Surv. S. Aust. Rep. Invest.,* 28.

FREYTAG, I. B., 1966: Proposed rock units for marine Lower Cretaceous sediments in the Oodnadatta region of the Great Artesian Basin. *Quart. geol. Notes, geol. Surv. S. Aust.,* 18, pp. 3-7.

FREYTAG, I. B., HEATH, G. R., & WOPFNER, H., 1967: Geological atlas of South Australia 1:250 000 series, Oodnadatta Sheet SG/53-15, Zone 5. *Geol. Surv. S. Aust.*

GEOLOGICAL SOCIETY OF AUSTRALIA, 1964: *Australian code of stratigraphic nomenclature,* 4th edition. *J. geol. Soc. Aust.,* 11, pp. 165-171.

GLAESSNER, M. F., & RAO, V. R., 1955: Lower Cretaceous plant remains from the vicinity of Mount Babbage, South Australia. *Trans. Roy. Soc. S. Aust.,* 78, pp. 134-140.

HARRIS, W. K., 1965: Basal Tertiary microfloras from the Princetown area, Victoria, Australia. *Palaeontographica B, 115,* pp. 75-106.

HARRIS, W. K., 1966: New and redefined names in South Australian Lower Tertiary stratigraphy. *Quart. geol. Notes, geol. Surv. S. Aust.,* 20, pp. 1-3.

HARRIS, W. K., 1971: Tertiary stratigraphic palynology, Otway Basin; 4 *in* The Otway Basin of southeastern Australia. *Spec. Bull. geol. Surv. S. Aust. Vic.,* pp. 67-87.

HARRIS, W. K., 1972: Early Tertiary microfloras from the Pirie-Torrens Basin. *S. Aust. Dep. Min. Rep.* 72/70 (unpubl.).

HARRIS, W. K., 1973: Tertiary non-marine dinoflagellate cyst assemblages from Australia. *Geol. Soc. Aust. spec. Publ.,* 4.

HEDBERG, H. D., 1972: International subcommission on stratigraphic classification, Reports Nos. 7a and b. *Lethaia, 5,* pp. 283-323.

JACK, R. L., 1925: Some developments in shallow water areas in the northeast of South Australia. *Geol. Surv. S. Aust. Bull. 11.*

JACK, R. L., 1930: Geological structure and other factors in relation to underground water supplies in portions of South Australia. *Geol. Surv. S. Aust. Bull. 14.*

JOHNS, R. K., 1968: Investigation of Lakes Torrens and Gairdner. *Geol. Surv. S. Aust. Rep. Invest. 31.*

JOHNS, R. K., & LUDBROOK, N. H., 1963: Investigation of Lake Eyre. *Geol. Surv. S. Aust. Rep. Invest. 24.*

KAPEL, A. J., 1966: The geology of the Cooper's Creek Basin. *APEA J., 1966,* pp. 71-75.

KENNY, E. J., 1934: West Darling District. A geological reconnaissance with special reference to the resources of subsurface water. *Geol. Surv. N.S.W., Miner. Resour.,* 36.

LINDSAY, J. M., & BONNETT, J. E., 1973: Tertiary stratigraphy of three deep bores in the Waikerie area of the Murray Basin. *Geol. Surv. S. Aust. Rep. Invest. 38.*

LINDSAY, J. M., & HARRIS, W. K., 1973: Fossiliferous marine and non-marine Cainozoic rocks from the eastern Eucla Basin, South Australia. *S. Aust. Dep. Min. Rep. 73/70* (unpubl.).

LUDBROOK, N. H., 1972: Age and environment of deposition of sample from S.A.D.M. Wooltana No. 1 at 239.39 m. *S. Aust. Dep. Min. Rep. 72/20* (unpubl.).

McGOWRAN, B., HARRIS, W. K., & LINDSAY, J. M. 1970: The Maslin Bay flora, South Australia. 1. Evidence for an early middle Eocene age. *N. Jb. Geol. Paläont. Mh. 8,* pp. 481-485.

McGOWRAN, B., LINDSAY, J. M., & HARRIS, W. K., 1971: Attempted reconciliation of Tertiary biostratigraphic systems, Otway Basin; *in* The Otway Basin of southeast Australia. *Spec. Bull. geol. Survs. S. Aust. Vic.,* pp. 273-281.

MARTIN, C. A., 1967: A descriptive summary of Moomba Gasfield. *Australas. Oil Gas J., 13,* pp. 23-26.

MOND, A., 1972: Shallow stratigraphic drilling in the Gason and Pandie Pandie 1:250 000 Sheet areas, South Australia, 1970. *Bur. Miner. Resour. Aust. Rec.* 1972/27 (unpubl.).

MULREADY, J. N., 1970: Alliance Petroleum Australia N.L., Packsaddle No. 1 well completion report. *S. Aust. Dep. Min. Envel.* 1437 (unpubl.).

OFFLER, C., 1969: Comparison of extant and fossil vegetative shoots. *Ph.D. thesis, Univ. Adel.* (unpubl.).

ROSE, G., O'CONNELL, P., & MENZIES, I. A., 1967: Geological atlas of Australia 1:250 000 series, Milparinka Sheet, SH/54-7. *Geol. Surv. N.S.W.*

SELLY, R. C., 1970: *Ancient Sedimentary Environments.* Chapman & Hall, London.

SENIOR, B. R., GALLOWAY, M. C., INGRAM, J. A., & SENIOR, D., 1968: The geology of the Barrolka, Eromanga, Durham Downs, Thargomindah, Tickalara and Bullow 1:250 000 Sheet areas, Queensland. *Bur. Miner. Resour. Aust. Rec.* 1968/35 (unpubl.).

SINGLETON, F. A., 1941: The Tertiary geology of Australia. *Proc. Roy. Soc. Vic.,* 53, pp. 1-126.

SOUTHCOTT, R. V., & LANGE, R. T., 1971: Acarine and other microfossils from the Maslin Eocene, South Australia. *Rec. S. Aust. Mus.,* 16(7), pp. 1-21.

SPENCER, B., 1896: *Report on the work of the Horn Scientific Expedition to Central Australia, Part 1.* Dulau, London.

SPRIGG, R. C., 1958: Petroleum prospects of western parts of Great Australian Artesian Basin. *Bull. Am. Ass. Petrol. Geol.,* 42, pp. 2465-2491.

STEPHENS, C. G., 1971: Laterite and silcrete in Australia: A study of the genetic relationships of laterite and silcrete and their comparison materials, and their collective significance in the formation of the weathered mantle soils, relief and drainage of the Australian continent. *Geoderma,* 5, pp. 5-52.

STIRTON, R., TEDFORD, R. H., & MILLER, A. H., 1961: Cenozoic stratigraphy and vertebrate palaeontology of the Tirari Desert, South Australia. *Rec. S. Aust. Mus.,* 14, pp. 19-61.

STOVER, L., & EVANS, P. R. 1973: Upper Cretaceous-Eocene spore-pollen zonation offshore Gippsland Basin, Australia. *Geol. Soc. Aust. spec. Publ.,* 4.

STOVER, L., & PARTRIDGE, A. D., 1973: Tertiary and late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proc. Roy. Soc. Vic.* (in press).

TATE, R., 1882: Supplementary water; *in* Plant-bearing beds between Lake Frome and the Barrier Ranges. *Trans. Roy. Soc. S. Aust.,* 5, p. 98.

THORNTON, R. C. N., 1972: Lower Cretaceous sedimentary units beneath the western Murray Basin. *Quart. geol. Notes, geol. Surv. S. Aust.* 44, pp. 5-11.

TOWNSEND, I. J., 1967: Delhi-Santos Moomba No. 4 well, lithological sequence — surface to 1000 ft. *S. Aust. Dep. Min. Rep.* 742 (unpubl.).

TRICART, J., 1961: Observations sur le charriage des materiaux grossiers par les cours d'eau. *Rév. Géomorph. dynam.,* 12, pp. 1-15.

WILLIAMS, G. E., & POLACH, H. A., 1971: Radiocarbon dating of arid-zone calcareous paleosols. *Bull. geol. Soc. Am.,* 82, pp. 3069-3086.

WHITEHOUSE, F. W., 1940: Studies in the late geological history of Queensland. *Pap. Dep. Geol. Univ. Qld, 2(1).*

WHITEHOUSE, F. W., 1954: The geology of the Queensland portion of the Great Australian Artesian Basin. Appendix G *in* Artesian water supplies in Queensland. *Dep. Co-ord. Gen. Pub. Works Qld, parl. Pap. A,* 56-1955.

WOODARD, G. D., 1955: The stratigraphic succession in the vicinity of Mt Babbage Station, South Australia. *Trans. Roy. Soc. S. Aust.,* 78, pp. 8-17.

WOOLNOUGH, W. G., & DAVID, T. W. E., 1926: Cretaceous glaciation in Central Australia. *Quart. J. geol. Soc. Lond.,* 82, pp. 332-435.

WOPFNER, H., 1958: The geology of the Innamincka Dome. *S. Aust. Dep. Min. Envel.* 74 (unpubl.).

WOPFNER, H., 1960: On some structural development in the central part of the Great Australian Artesian Basin. *Trans. Roy. Soc.. S. Aust.,* 83, pp. 179-193.

WOPFNER, H., 1963: Post-Winton sediments of probably Upper Cretaceous age in the central Great Artesian Basin. *Trans. Roy. Soc. S. Aust.,* 86, pp. 247-254.

WOPFNER, H., 1966: A case history of the Gidgealpa gas field, South Australia. *Australas. Oil Gas J.,* 12, pp. 29-53.

WOPFNER, H., 1968: Cretaceous sediments on the Mt Margaret Plateau and evidence for neotectonism. *Quart. geol. Notes, geol. Surv. S. Aust.* 28, pp. 7-11.

WOPFNER, H., (in press): Post-Eocene history and stratigraphy of northeastern South Australia. *Trans. Roy. Soc. S. Aust.,* 98.

WOPFNER, H., & CORNISH, B. E., 1967: S.A.G. Fortville No. 1, well completion report. *S. Aust. Dep. Min. Rep. Invest.* 29, pp. 1-62.

WOPFNER, H., FREYTAG, I. B., & HEATH, G. R., 1970: Basal Jurassic-Cretaceous rocks of western Great Artesian Basin, South Australia: stratigraphy and environment. *Bull. Am. Ass. Petrol. Geol.,* 54, pp. 383-416.

WOPFNER, H., & TWIDALE, C. R., 1967: Geomorphological history of the Lake Eyre Basin; *in* JENNINGS, J. N., & MABUTT, J. A. (Eds), *Landform studies from Australia and New Guinea,* pp. 118-143. ANU Press, Canberra.

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